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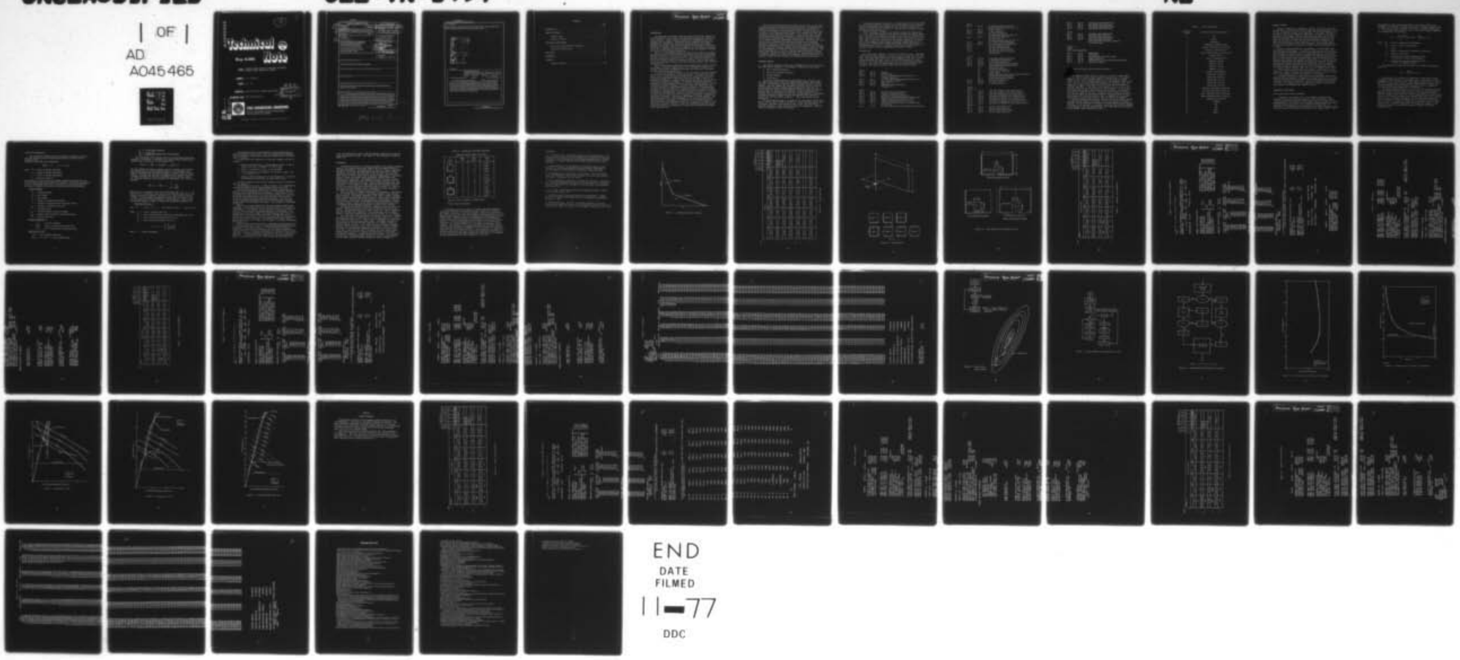

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A computer program was developed to determine the nonlinear dynamic response of reinforced concrete slabs subjected to blast pressure loading. Given the explosive parameters and geometry of the slab, the program computes the blast environment and the structural resistance, mass, and stiffness of the slab and solves for the dynamic response. The program contains optimization subroutines that provide for automatic optimum design of least-cost structural slabs. The program will assist engineers in the design and analysis of facilities over

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A computer program was developed to de[illegible] nonlinear dynamic response of reinforced concrete slabs subjected to blast pressure loading. Given the explosive parameters and geometry of the slab, the program computes the blast environment and the structural resistance, mass, and stiffness of the slab and solves for the dynamic response. The program contains optimization subroutines that provide for automatic optimum design of least-cost structural slabs. The program will assist engineers in the design and analysis of facilities that are intended to contain the effects of accidental explosions. The report gives a user's guide and sample problems with data input and program output.

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INTRODUCTION

The Department of Defense (DOD) has numerous facilities engaged in the production of various types of explosives and munitions used by military services. In most cases the production of ammunition utilizes assembly line procedures. Projectiles pass through various stages of preparation: filling with explosive, fuzing, marking, and packing. Hazardous operations, such as the filling of the projectile case with an explosive in a powder form and the compaction of the powder by hydraulic press, are accomplished in protective cells that are intended to confine the effects of an accidental explosion.

Most of the existing production facilities were built in the 1940s. With few exceptions, the manufacturing technology and existing equipment represent the state of the art as of 1940. The production equipment was operated extensively during World War II, again during the Korean conflict, and recently during the Southeast Asia war. Much of this equipment and the housing structures have been operating beyond their designed capacities [1].

DOD is conducting an ammunition plant modernization program [2] that is intended to greatly enhance safety in the production plants by protective construction, automated processing, and reduction of personnel involved in hazardous operations.

In 1969 a joint-service manual [3] was published to provide guidance to the structural designers of munition plants. The objectives of the manual were to establish design procedures and construction techniques to prevent propagation of explosions from one building, or part of a building, to another; to prevent mass detonations; and to provide protection for personnel and equipment. The manual establishes blast-load parameters for designing protective structures, provides methods for calculating the dynamic response of concrete walls, and establishes construction details for developing required strength. The design method accounts for close-in effects of a detonation with its associated high pressures and nonuniformity of loading on protective barriers. A detailed method for assessing the degree of protection afforded by a protective facility did not exist prior to this manual's publication; consequently, the manual represents a significant improvement in design methods. The simplifications made in the development of the design procedures have been presented in the manual. The analysis of a structure using the design procedure will generally result in a conservative estimate of the structure's capacity; therefore, structures designed using these procedures will generally be adequate for blast loads exceeding the assumed load conditions [3].

Even with the simplifications presented in Reference 3, the computational procedures are complex and time-consuming. An automated procedure was required to give structural designers the capability to perform rapid analysis of the structural safety of blast-resistant construction. The design parameters interact in a complex way since the procedure is both nonlinear and dynamic. From a design point of view an optimization procedure was required to minimize cost and maximize safety since blast-resistant construction has been reported to cost 3 to 5 times as much as conventional construction. Therefore, the first objective was to automate the analysis procedures for determining structural response of reinforced concrete slabs having a bilinear stiffness representation and subjected to blast shock and gas pressures. Concrete slabs are the basic element forming sidewalls, roofs and floors of cells designed to confine the effects of accidental explosions. The second objective was to provide an optimum design procedure for laced and unlaced reinforced concrete slabs that will automatically produce a least-cost design for a given slab geometry, material properties, and explosive weight for both feasible and nonfeasible starting points.

COMPUTER PROGRAM

The computer program was written in FORTRAN IV for use with Control Data 6600 series computers. The program is composed of four areas:

1. Blast Load Determination
2. Structural Analysis Parameters
3. Dynamic Response
4. Optimization

The blast-load determination is accomplished by subroutines BLA, PIC, SGRID, HBA, RATIO, GRID, GAS INTERP, EQUIV, HEDATA, ARDC, SHOCK, and TNT. The subroutines read the explosive weight and type and cell geometry, and then compute the equivalent spherical weight of TNT and the equivalent pressure loading using the geometry of the wall and charge location. Both the shock pressure and its duration and the gas pressure and its duration are calculated. Using the duration and pressure data for both shock and gas, the program computes an equivalent triangular pressure loading for each part and adds both together to produce the resultant shown in Figure 1. The total impulse is then determined.

The structural analysis is accomplished by subroutines SSTIFF, LACE, DOOR 1, DOOR 2, DOOR 3, DOOR 4 and DOOR 5. These routines compute the stiffness, resistance, and equivalent mass of the slab using input material properties. Both flexure and shear are considered. Openings (doors or windows) in walls are allowed.

The dynamic response calculation is accomplished in subroutine RESP. The program determines the response of the slab modeled as an equivalent dynamic single-degree-of-freedom system with bilinear stiffness and pressure loading as shown in Figure 1. The solution technique is based on a Newmark iteration method.

When a thickness of sand is specified for composite construction (i.e., two slabs with sandfill), the program computes the impulse capacity of the first slab using half the mass of the sand as acting with the wall. Figures 6-38 and 6-39 of Reference 3 give the attenuation of the blast wave on sand for evaluation of the impulse capacity of the second wall. The optimization of an initial design is accomplished in subroutines OPT, MINIMZ, PMINZ, DMINZ, GETE, SUMRY, TLEFT, AND GCOMP. The methodology used is that of a penalty function with individual minimization sequences being accomplished by the Powell method.

Program Input

The program input consists of five or six cards per case. Additional cases can be grouped together. Two blank cards are used after the last case. The users guide contained in the program is given here to assist in understanding the input. Card format is 8F10.0 except as noted. Figure 2a is an input data sheet to be used in conjunction with Figures 2b and 2c, which show the slab geometry and orientation that must be followed. The input required for each card is described below.

CARD 1		
COL 2	COL 68	HEADING
COL 69	COL 70	OPTIMIZATION = 1.
COL 71	COL 72	FLAG EQ 0 FOR PRESSURE CALCULATION EQ 1. FOR INPUT PRESSURE
COL 73	COL 74	FLAG FOR REBAR DIAMETER RATHER THAN AREA = 1
COL 75	COL 76	FLAG FOR IMPULSE GRID = 1
COL 77	COL 78	DOOR FLAG = 1
COL 79	COL 80	DOOR EQUILIBRIUM ITERATION = 1 OTHERWISE = 0
CARD 2		
COL 1	COL 10	WEIGHT OF ACTUAL EXPLOSIVE LB
COL 11	COL 20	EXPLOSIVE NUMBER SEE TABLE 2
COL 21	COL 30	EXPLOSIVE LENGTH/DIAMETER RATIO
COL 31	COL 40	PROJECTILE CASE WEIGHT/EXPLOSIVE WEIGHT RATIO
COL 41	COL 50	AMBIENT PRESSURE PSIA (DEFAULT 14.69 PSI)
COL 51	COL 60	AMBIENT TEMPERATURE^{o}C (DEFAULT 20^{o})
COL 61	COL 70	ALTITUDE KFT (WHEN PRESSURE AND TEMPERATURE NOT SPECIFIED)
COL 71	COL 80	EFFECTIVE IMPULSE FRACTION COMPOSITE CONSTRUCTION

CARD 3

COL 1	COL 10	RA DISTANCE CHARGE TO WALL FT
		OR EQUAL IMPULSE PSI-MS IF FLAG = 1.0
COL 11	COL 20	H WALL HEIGHT FT
COL 21	COL 30	EL WALL LENGTH FT
COL 31	COL 40	HLIT HEIGHT CHARGE FT
		OR EQUAL PRESSURE PSI IF FLAG = 1.0
COL 41	COL 50	ELLIT DISTANCE CHARGE TO
		LEFT SIDE WALL FT
		OR EQUAL DURATION (MS) IF FLAG = 1.0
COL 51	COL 60	CELL VOLUME FOR GAS PRESSURE
COL 61	COL 70	CELL VENT AREA FOR GAS PRESSURE
COL 71		EQ1 FOR FLOOR REFLECTION
COL 72		EQ1 FOR ROOF REFLECTION
COL 73		EQ1 FOR LEFT WALL REFLECTION
COL 74		EQ1 FOR RIGHT WALL REFLECTION
		OTHERWISE EQ 0

CARD 4

COL 1	COL 10	FC DYNAMIC CONCRETE STRESS PSI
COL 11	COL 20	FY DYNAMIC STEEL STRESS PSI
COL 21	COL 30	TC THICKNESS CONCRETE IN.
COL 31	COL 40	THETA ALLOWABLE ROTATION DEGREES
COL 41	COL 50	NSIDE NUMBER OF SIDES WALL FIXED
	1.0	BOTTOM SIDE FIXED
	2.0	BOTTOM AND SIDE FIXED
	3.0	2 SIDES AND BOTTOM FIXED
	4.0	4 SIDES FIXED
	5.0	SIMPLE SUPPORTED BEAM FIXED AT TOP AND BOTTOM
	6.0	FIXED BEAM AT TOP AND BOTTOM
	7.0	BEAM BOTTOM FIXED TOP SIMPLE
COL 51	COL 60	TSAND SAND THICKNESS FT
COL 61	COL 70	BL LACING LENGTH
COL 71	COL 80	SL LACING SPACING IN.

CARD 5

OPTION 2 = 0

COL 1	COL 10	ASVT AREA VERTICAL STEEL BLAST SIDE/FT
COL 11	COL 20	ASVB AREA VERTICAL STEEL OPPOSITE SIDE/FT
COL 21	COL 30	ASHT AREA HORIZONTAL STEEL BLAST SIDE/FT
COL 31	COL 40	ASHB AREA HORIZONTAL STEEL OPPOSITE SIDE/FT
COL 41	COL 50	DVT DEPTH TO VERTICAL STEEL BLAST SIDE IN.
COL 51	COL 60	DVB DEPTH TO VERTICAL STEEL OPPOSITE SIDE IN.
COL 61	COL 70	DHT DEPTH TO HORIZONTAL STEEL BLAST SIDE IN.
COL 71	COL 80	DHB DEPTH TO HORIZONTAL STEEL OPPOSITE SIDE IN.

OPTION 2 = 1

COL 1	COL 10	BAR SIZE VERT OPPOSITE SIDE
COL 11	COL 20	BAR SIZE VERT BLAST SIDE
COL 21	COL 30	BAR SIZE HORIZ OPPOSITE SIDE
COL 31	COL 40	BAR SIZE HORIZ BLAST SIDE

COL 41	COL 50	BAR SPACING VERT OPPOSITE SIDE
COL 51	COL 60	BAR SPACING VERT BLAST SIDE
COL 61	COL 70	BAR SPACING HORIZ OPPOSITE SIDE
COL 71	COL 80	BAR SPACING HORIZ BLAST SIDE

CARD 6

COL 1	COL 10	BAR DEPTH VERT OPPOSITE SIDE
COL 11	COL 20	BAR DEPTH VERT BLAST SIDE
COL 21	COL 30	BAR DEPTH HORIZ OPPOSITE SIDE
COL 31	COL 40	BAR DEPTH HORIZ BLAST SIDE DEPTH FROM OUTTER CONCRETE SURFACE TO CENTER OF BAR

OPTION 4 = 1
CARD 6
BLAST DOOR PARAMETERS

COL 1	COL 10	DOOR HEIGHT
COL 11	COL 20	DOOR WIDTH
COL 21	COL 30	DISTANCE FROM LEFT SIDE TO DOOR
COL 31	COL 40	DOOR REACTION OR
COL 41	COL 50	DOOR RESISTANCE FOR CALCULATION OF REACTION
COL 51	COL 60	DISTANCE TO FLOOR

Note: All values are fixed point, except for reflection code and options.

The explosive number (Card 2) refers to the list of explosives in Table 1. This is used to compute explosive equivalence. The length/diameter ratio for an explosive sphere is 0.0, which gives a shape factor of 1.0. For an uncased explosive the case explosive weight ratio is 0. For sea level calculations the ambient air pressure, P_{amb}, and temperature, T_{amb}, and altitude can be left blank and will default to 14.69 psi and 20°C. If the flag in the heading card is set to 1, the impulse, duration, and pressure will be read on Card 3. If the flag is left blank, the charge to wall distance, charge height, and distance from the left side will be read. If NSIDE is left blank, the program will sum the number of reflecting sidewall surfaces specified on Card 3. The separate use of NSIDE is helpful when a frangible wall is present, which creates a shock reflection but does not provide any support.

When optimization and composite construction are specified together, the program will optimize the design to resist the given or computed impulse. For the case when two walls are acting together each resisting a portion of the impulse it is necessary to specify the effective impulse to be applied to the wall under design. The total impulse is multiplied by the decimal number specified on Card 2.

Table 1. List of Explosives

Explosive Number	Explosive Name and Composition
1	TNT
2	TNETB
3	EXPLOSIVE D
4	PENTOLITE (PETN/TNT 50/50)
5	PICRATOL (EXPLOSIVE D/TNT 52/48)
6	CYCLOTOL (RDX/TNT 70/30)
7	COMP B (RDX/TNT/WAX 59.4/39.6/1.0)
8	RDX/WAX (98/2)
9	COMP A-3 (RDX/WAX 91/9)
10	TNETB/AL (90/10)
11	TNETB/AL (78/22)
12	TNETB/AL (72/28)
13	TNETB/AL (65/34)
14	TRITONAL (TNT/AL80/70)
15	RDX/AL/WAX (88/10/2)
16	RDX/AL/WAX (89/20/2)
17	RDX/AL/WAX (74/21/5)
18	RDX/AL/WAX (74/22/4)
19	RDX/AL/WAX (62/33/5)
20	TORPEX II (RDX/TNT/AL 42/40/18)
21	H6 (RDX/TNT/AL/WAX 45/29/21/5)
22	HBX-1 (RDX/TNT/AL/WAX 40/38/16/5)
23	HBX-3 (RDX/TNT/AL/WAX 31/29/35/5)
24	TNETB/RDX/AL 39/26/35)
25	ALUMINUM
26	WAX
27	RDX
28	PETN
29	TETRYL

Example Problems

The first example is a sidewall of a blast cell with a roof. The concrete wall is 32 feet long, 12 feet high, and 2 feet thick with 4 feet of sand in composite action. Note that half of the input thickness of the sand is used by the program as added mass to the wall. The wall is restrained at the floor, roof, and left side; the right side is free. Since the three-side-fixed option condition assumes the sides and the bottom to be fixed, the wall must be reoriented when filling out the input form (Figure 3). Thus, a height of 32 feet and a length of 12 feet are used to properly orient the free edge. An allowable support rotation of 12 degrees is given which assumes lacing reinforcement will be used.

Figure 4 gives the results of the analysis. A blast impulse of 2,406 psi-ms was determined. The section properties are given. Since shear exceeds the allowable, lacing must be provided for the difference. The yield-line location is given. An ultimate resistance of 101.9 psi and a stiffness of 825 psi were determined. The impulse capacity of the wall is 4,365 psi-ms, which is much greater than the loading of 2,406 psi-ms; this indicates the design is conservative. If a second wall of the same construction were present and acted with the first in composite construction, Figures 6-38 and 6-39 of Reference 3 could be used to determine its impulse capacity and the total capacity of both walls; the scaled values of impulse, sand, and concrete thicknesses are used.

Figure 5 gives the input data for a roof of a blast cell 32 by 15 feet. The 32-foot side is used as the height to agree with the fixity condition. Figure 6 presents the computer analysis. In this case sand fill is not present, and the wall response is calculated.

A maximum deflection of 18.98 inches was determined; this can be compared with the allowable 12-degree-rotation deflection of 18.6 inches. Since the maximum deflection exceeds the 12-degree-rotation deflection, collapse of the wall is indicated. Average and maximum scale velocity are given. The appendix gives two additional examples, wherein hand calculations are compared with computer results.

THEORETICAL DEVELOPMENT

Blast Loads and Structural Response

In general, the methods used in the computer program follow Reference 3, and, as such, the accuracy of both is the same. Since these are discussed in detail in References 3 and 4, they will not be presented here. The solution of the dynamic response equation of motion has been found to agree very closely with the response chart of Reference 3. Additionally, the solution covers a wider range and, thus, is more accurate in the areas not defined by the response chart. When

the loading is less than one hundredth of the natural period, the response is determined by impulse equilibrium. The basic dynamic model is limited to one mode of response and does not consider higher modes.

The ultimate moment capacity, M_u, of the slab is based on Equation 5-4 of Reference 3, as follows:

$$M_u = \frac{(A_s - A'_s)f_s}{b}\left(d - \frac{a}{2}\right) + \frac{A'_s f_s}{b}(d - d')$$

where A'_s = area of compression reinforcement

A_s = area of tension reinforcement

b = width

a = depth of equivalent rectangular stress block

f_s = design steel stress

d = distance from extreme compression fiber to centroid of tension reinforcement

d' = distance from extreme compression fiber centroid to compression fiber

This equation for equal reinforcement in tension and compression reduces to

$$M_u = \frac{A'_s f_s}{b}(d - d')$$

The action of the concrete in compression is neglected, because crushing at high rotations is assumed to occur. This results in disengagement of the concrete cover. When support rotations are restricted by lack of lacing, this equation becomes conservative. However, the more conventional concrete analysis procedures were not included to conform with the methodology given in Reference 3.

The blast impulse computation is restricted to a geometry in which the slab height-to-length ratio is greater than 0.2. The modification made by the Naval Surface Weapons Center to the original Picatinny Arsenal Program did not affect the results significantly for most cases. However, it did remove several minor problem areas, such as the location of the charge. The blast impulse has all the limitations associated with the original Picatinny programs that are caused by limitations in the test data. It assumes the charge is an equivalent sphere of TNT. Shape effects, explosive equivalence, and explosive casings are considered, but only in an empirical manner as a result of limited available data.

Structural Optimization

The optimization problem consists of finding the least-cost structure that satisfies all the design constraints; or, stated in optimization terms:

Find $\vec{X}$ such that $M(\vec{X})$ is a minimum and

$$g_i(\vec{X}) \leq 0 \qquad i = 1, 2, N$$

where $\vec{X}$ = vector of design variables

N = number of design constraints

g = vector of design constraints

M = objective function

Specifically for this problem, the design variables selected are areas of steel reinforcement and thickness of concrete. The design constraints are the flexural and shear limits. The objective function consists of the costs of formwork and concrete flexural and shear reinforcement.

Fixed Variables

W = explosive weight

H = wall height

EL = wall length

h = height of explosive above floor

ℓ = distance of explosive from left side of wall

R_a = distance of explosive from wall

I = reflection code

f_{dc} = ultimate dynamic concrete strength

f_{dy} = dynamic yield strength of reinforcing steel

θ = rotation criterion

Design Parameters, X

$$X = \begin{cases} t_c & \text{concrete thickness} \\ AV & \text{area of vertical reinforcing steel} \\ AH & \text{area of horizontal reinforcing steel} \end{cases}$$

Constraints, g (X)

$\delta(X) = \delta(\theta)$, maximum deflection

$V(X) \leq VC$ for $\theta \leq 2$ deg, maximum shear

$t_c \geq$ 12, minimum thickness

$\left.\begin{array}{l} AV \geq 0.0025\ bd \\ AH \geq 0.0025\ bd \end{array}\right\}$ minimum steel reinforcement

The methodology [5,6] selected uses the unconstrained minimization approach. The problem is converted to an unconstrained minimization by constructing a function, ϕ, of the general form

$$\phi(\vec{X}, r) = M(\vec{X}) + P[g_1(\vec{X}), \ldots, g_n(\vec{X}), r]$$

For this problem the interior penalty function technique was selected. This methodology is suitable when gradients are not available, and, because the method uses the feasible region, a useable solution always results. The objective function is augmented with a penalty term that is small at points away from the constraints in the feasible region, but increases rapidly as the contraints are approached. The form is as follows:

$$\phi(\vec{X}, r) = M(\vec{X}) - r \sum_{j=1}^{N} \frac{1}{g_j(\vec{X})}$$

where M is to be minimized over all $\vec{X}$ satisfying g $(\vec{X}) \leq 0$, j = 2 ... N. Note that if r is postive, then, since at any interior point all of the terms in the sum are negative, the effect is to add a positive penalty to $M(\vec{X})$. As the boundary is approached, some g $(\vec{X})$ will approach zero, and the penalty will increase rapidly. The parameter, r, will be made successively smaller in order to obtain the constrained minimum of M.

<u>Objective Function, F</u>

$$\text{Cost} = F = H \bullet EL \bullet t_c \bullet C_c + (AV + AH)(EL \bullet H)C_s + (A_s)(EL \bullet H)C_L$$

where C_c = cost of concrete (\$/cu ft)

C_s = cost of horizontal and vertical reinforcement (\$/cu in.)

C_L = cost of lacing reinforcement (\$/cu in.)

A_s = area lacing reinforcement (\$/cu in.)

$$\phi = F + r \sum_{j=1}^{N} \left[\frac{1}{g_j(X)} \right]$$

where r = penalty parameter.

The program requires a starting point in the feasible region before optimization can proceed. This is accomplished automatically by the program by incrementing the design variables until a feasible point is reached.

An algorithm which comprises the steps most commonly used is as follows:

1. Given a starting point, X_o, satisfying all $g_j(X) < 0$ and an initial value for r, minimize ϕ to obtain X_{min}.
2. Check for convergence of X_{min} to the optimum.
3. If the convergence criterion is not satisfied, reduce r by $r \leftarrow rc$, where $c < 1$.
4. Compute a new starting point for the minimization, initialize the minimization algorithm, and repeat from step 1.

The logic diagram for the interior penalty functions technique is shown in Figure 7.

The minimization for $\phi(X, r)$ shown in Figure 7 is accomplished by a method developed by Powell using conjugate directions [5,6].

Powell's method can be understood as follows: Given that the function has been minimized once in each of the coordinate directions and then in the associated pattern direction. Discard one of the coordinate directions in favor of the pattern direction for inclusion in the next m minimizations, since this is likely to be a better direction than the discarded coordinate direction. After the next cycle of minimizations, generate a new pattern direction, and again replace one of the coordinate directions. This process is illustrated in Figure 8.

Figure 9 is a logic diagram for the unconstrained minimization algorithm. The pattern move is constructed in block A, then used for a minimization step (blocks B and C), and then stored in S_n (block D) as all of the directions are up-numbered and S_1 is discarded. The direction S_n will then be used for a minimizing step just before the construction of the next pattern direction. Consequently, in the second cycle, both X and Y in block A are points that are minima along S_n, the last pattern direction. This sequence will impart special properties to $S_{n+1} = X - Y$ that are the source of the rapid convergence of the method.

Figure 9 shows a block requiring a one-dimensional minimization of α^* of the function $\phi(\vec{X} + \alpha S_q)$. The one-dimensional minimization uses a four-point cubic interpolation. It finds the minimum along the direction S_q, where $\vec{X}$ is the coordinate of the previous minimum. By trial and error it finds three points with the middle one less than the other two. It makes a quadratic interpolation, and then a cubic interpolation. If the actual function evaluated at the new interpolated point is not sufficiently close to that of the preceding point or if

it is not sufficiently close to the interpolated function, then another cubic interpolation is made. The logic for this algorithm is shown in Figure 10.

DISCUSSION

The objective function is linearly dependent on the design variables; however, the constraints are both linearly and nonlinearly related to the design variables. The minimum area of steel is a linear constraint. Figures 11 and 12 show the shear stress and the deflection as being nonlinearly related to the thickness of the concrete. Note that the shear stress is almost linear and is constant (independent of thickness). Figure 13 shows the useable region bounded by flexure, shear, and minimum steel constraints. The optimum least-cost solution is shown. This specific example solution considers an unlaced section; thus, the maximum shear constraint is active. Laced sections eliminate the shear constraint. If the number of sides supported were increased from N=2 to N=3, the design space would change as shown in Figure 14. There are two regions that are useable areas. Obviously, the lower one offers the least cost and, therefore, is more desirable.

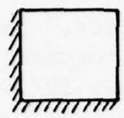
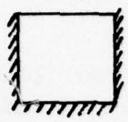
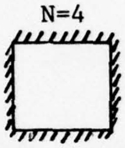
There is clearly a complex interaction of constraints. Unfortunately, the optimum solution found by the program depends on the starting point selected. The program converges on the closest relative optimum. Several alternative starting points should be used to verify a questionable optimum. Revising the design parameters could possibly shift the constraints such that only one useable solution would appear. However, a slight increase in shear stress (10%) can significantly reduce cost by allowing the near-optimum nonfeasible solution to be accepted.

The dual-space problem of finding a useable solution is limited to unlaced concrete slabs only because lacing eliminates the shear constraint. Nonautomated design for these conditions is almost impossible when one considers the complexity of the design space and the large number of iterations required when an initial solution is not feasible.

Cost data used in the program can be selected by the user. However, the data used herein is based on work by Picatinny Arsenal on contract with Ammann and Whitney [7]. Table 2 shows a comparison of unlaced and laced concrete walls with and without sand. The example considers a 15-foot-high by 12-foot-wide wall subjected to a 200-psi, 10-ms triangular loading function. In all cases the laced concrete (12-degree rotation) is less expensive than unlaced (2-degree rotation) designs. The costs for sand/concrete composite construction are for only the front wall. When the rear wall is included, the costs almost double, thereby making this form of construction unsuitable for relatively low pressure loadings. It should be pointed out that, for the N=3 and 4 conditions, the optimum design selected is actually a near optimum with the shear capacity slightly exceeded as shown in Figure 15.

Table 2. Comparison of Optimum Solutions

(200 psi; 10 ms; wall, 12L x 15H)

N Side	Theta (°)	Sand (in.)	Cost ($)
N=2	2	0	3,290
	12	0	2,289
	2	24	2,209[a]
	12	24	1,856[a]
N=3	2	0	2,753[b]
	12	0	2,019
	2	24	1,944[a,b]
	12	24	1,943[a]
N=4	2	0	2,001[b]
	12	0	1,958
	2	24	2,001[a,b]
	12	24	1,943[a]

[a]One wall only in composite construction.

[b]Shear capacity exceeded.

The program contains an option to analyze walls with openings. During many analyses it was noted that blast doors with resistances much higher than those of the walls transfer significant reactions to the walls such that the walls are incapable of accepting these and fail. Computational problems arise in the program when this happens in that yield regions cannot be brought into equilibrium by yield analysis methods. To avoid termination of the solution at this point the door resistance is reduced automatically by a factor of 2 to reduce the reaction. This usually allows for a successful termination. Unfortunately, this destroys the original starting point for optimization, and creates problems when a nonfeasible low-cost solution is lost and cannot be used to provide direction. It is, therefore, not possible to perform optimization solutions of walls with openings. Generally, it has been found that compatible designs occur when the door is designed to have approximately the same resistance as the wall.

REFERENCES

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4. Civil Engineering Laboratory. Technical Note TN-1434: Development of a computer program for the dynamic nonlinear response of reinforced concrete slabs under blast loading, by J. M. Ferritto. Port Hueneme, Calif, Apr 1976.

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7. Picatinny Arsenal. TR-4441: Preliminary estimate of concrete thickness and construction costs of laced reinforced concrete structures, by R. Dede, R. Dobbs, N. Porcaro, and J. Rindner. Dover, N.J., Oct 1972.

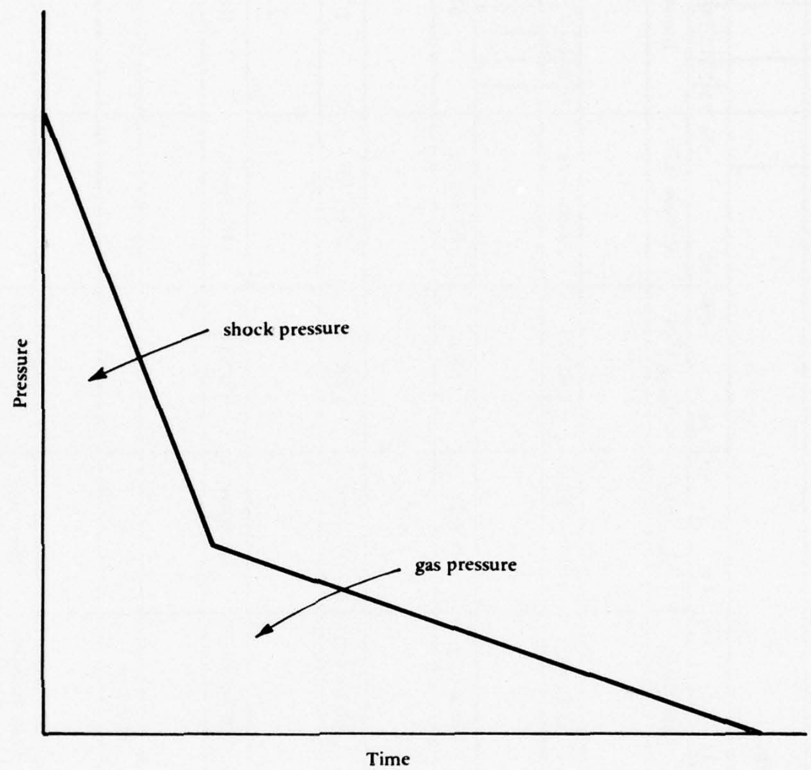
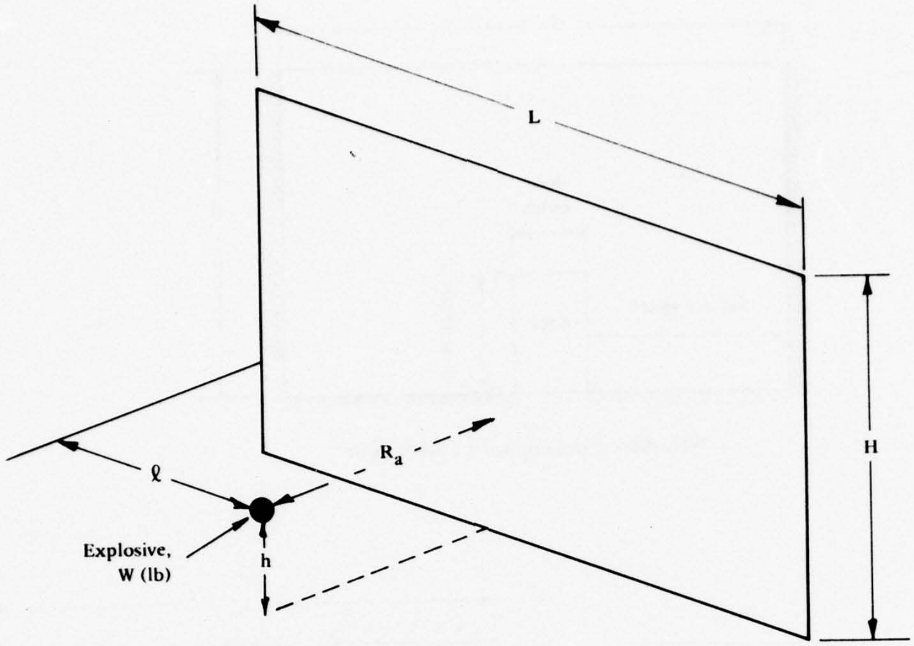


Figure 1. Equivalent pressure loading.

CARD	1 — 10	11 — 20	21 — 30	31 — 40	41 — 50	51 — 60	61 — 70	71 — 80
								OPTIONS 0 to 1: Optimum, P or I*, A_s or D, I Grid, Opening, Door Pr
1	Heading							
	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 72 73 74 75 76 77 78 79 80
	W (lb)	Expo No.	l/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (^oC)	Altitude (kft)	Impulse Effective
2								
	R_a (ft)/I (psi-ms)*	H (ft)	**L (ft)**	h (ft)/P_o (psi)*	l (ft)/t_o (ms)*	Cell Vol	Vent Area	F R L R
3								
	F_{dc} (psi)	F_{dy} (psi)	T_c (in.)	Theta (deg)	N Side	t Sand	*Bl. Lacing*	**SL Lacing**
4								
	A_sVT (in.^{2}/ft)	A_sVB (in.^{2}/ft)	A_sHT (in.^{2}/ft)	A_sHB (in.^{2}/ft)	D'VT (in.)	D'VB (in.)	D'HT (in.)	D'HB (in.)
5a								
or								
	VT Bar No.	VB Bar No.	HT Bar No.	HB Bar No.	VT Space	VB Space	HT Space	HB Space
5b								
	D'VT (in.)	D'VB (in.)	D'HT (in.)	D'HB (in.)				
5b								
	Door Height	Door Width	Dist to Left	Door Reaction	Door RU	Dist to Floor		
6								

Figure 2a. Input data form.



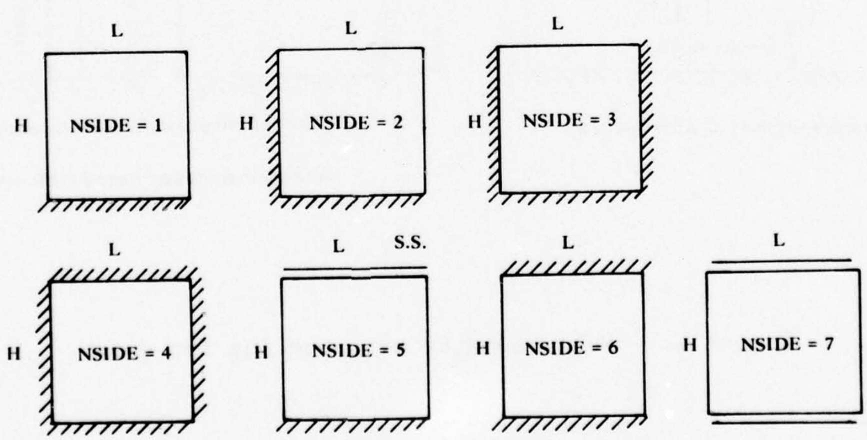
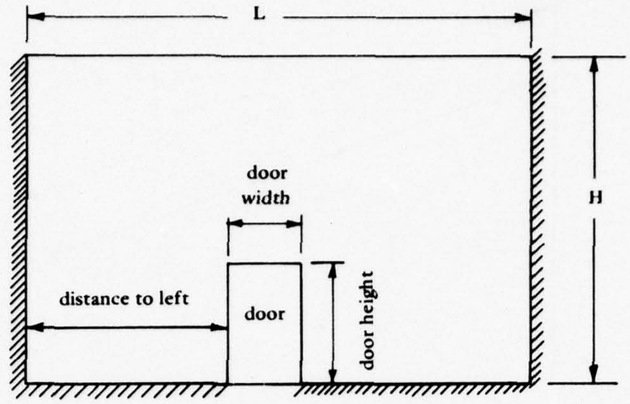
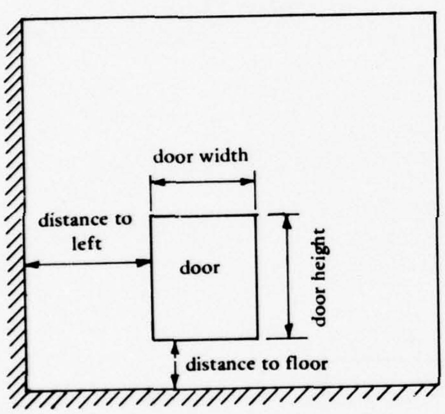


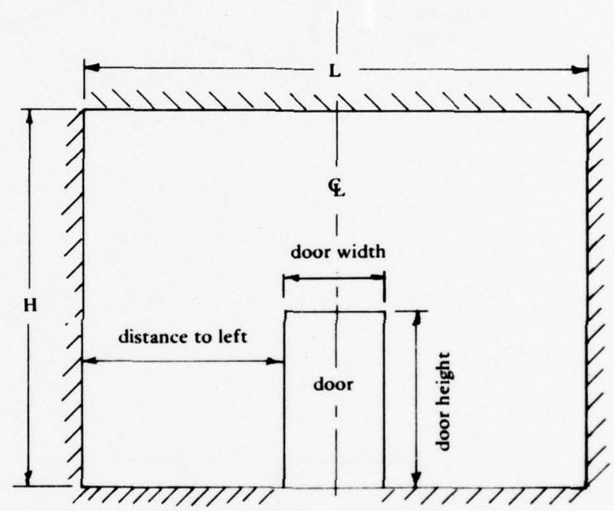
Figure 2b. Wall geometry.



Wall three sides supported with door.



Two sides supported with opening.



*Note opening must be in center of wall.

Wall four sides supported with opening.

Figure 2c. Wall geometry with opening for door.

OPTIONS 0 or 1

CARD	1–10	11–20	21–30	31–40	41–50	51–60	61–70	Optimum	P or I*	A_s or D	I Grid	Opening	Door Pr
1	Heading	Test Case, Example 1											
	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 72	73 74	75 76	77 78	79 80	
	W (lb)	Expo No.	l/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (°C)	Altitude (kft)	Effective Impulse					
2	310	1.0	0.										
	R_a (ft)/I (psi-ms)*	H (ft)	L (ft)	h (ft)/P_o (psi)*	l (ft)/t_o (ms)*	Cell Vol	Vent Area	F R L R					
3	3.	32.	12.	17.	3.			1 0 1 1					
	F_{dc} (psi)	F_{dy} (psi)	T_c (in.)	Theta (deg)	N Side	t Sand	Bl. Lacing	Sl. Lacing					
4	5000.	48000.	24.	12.	3.	4.							
	A_sVT (in.^{2}/ft)	A_sVB (in.^{2}/ft)	A_sHT (in.^{2}/ft)	A_sHB (in.^{2}/ft)	D'VT (in.)	D'VB (in.)	D'HT (in.)	D'HB (in.)					
5a	1.58	1.58	1.58	1.58	2.	2.	3.	3.					

Figure 3. Computer form, Example 1.

Figure 4. Computer results, Example 1.

```
 T E S T   C A S E,   E X A M P L E 1
TNT

EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  310.0
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
             KCAL/G       C      H      N      O     AL
   1  1.000 -.078400   .370   .022   .185   .423 0.000

PAMB(PSIA)=  14.69         TAMB(C)=  20.00


SHOCK WAVE CALCULATION

INPUT PARAMETERS                            CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)         =   310.0         ADJUSTED WT(LB TNT)  =   310.0
EXPLOSIVE NUMBER          =      1          HE ENERGY FACTOR     =   1.000
L/D RATIO                 = -0.             CHARGE SHAPE FACTOR  =   1.000
CASE/CHARGE WT RATIO      = -0.             CASE WEIGHT FACTOR   =   1.000
CHAMBER PRESSURE(PSIA)=      14.69          PRESSURE SCALE FACTOR=   1.000
CHAMBER TEMP(C)           =   20.00         DISTANCE SCALE FACTOR=   .1477
ALTITUDE (KFT)            = -0.             TIME SCALE FACTOR    =   .1490
                                            NORMAL REFL FACTOR   =   10.47

DESIRED DISTANCE(FT)    =    3.000
                (CM)    =    91.44

 TIME AFTER   TIME AFTER    INCIDENT    NORM REFL
 EXPLOSION    SHOCK ARR    OVERPRESS    OVERPRESS
  (MSEC)       (MSEC)        (PSI)        (PSI)
   .1156      0.             2736      28.6323E+03
   .2442        .1287        862.9          9031
   .3086        .1930        543.7          5690
   .3729        .2573        353.0          3695
   .4372        .3216        230.9          2417
   .5015        .3860        148.8          1558
   .5659        .4503        91.67         959.4
   .6302        .5146        50.95         533.2
   .6945        .5789        21.48         224.9
   .7588        .6433       0.            0.

IMPULSE (PSI.MSEC)--
```

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.1156	0.	2736	28.6323E+03
.2442	.1287	862.9	9031
.3086	.1930	543.7	5690
.3729	.2573	353.0	3695
.4372	.3216	230.9	2417
.5015	.3860	148.8	1558
.5659	.4503	91.67	959.4
.6302	.5146	50.95	533.2
.6945	.5789	21.48	224.9
.7588	.6433	0.	0.

```
IMPULSE (PSI.MSEC)--
    INCIDENT =    351.9
    REFLECTED=     3683

.....CAUTION--CONTACT SURFACE HAS ARRIVED.
        DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 12.3181E-03

DISTANCE OF CHARGE FROM BLAST WALL          FT.              3.00
CHARGE WEIGHT                              LBS.            310.00
BLAST WALL HEIGHT                           FT.             32.00

BLAST WALL LENGTH                           FT.             12.00
HEIGHT OF CHARGE ABOVE GROUND               FT.             17.00
MIN. DIST. BETWEEN CHARGE + ADJ. WALL       FT.              3.00
REFLECTION CODE                                        1  0  1  1

         TOTAL  IMPULSE         2406.90 PSI-MS

         DURATION OF LOAD        7.64583  MSEC

         FICTITIOUS F   K PRESSURE      629.59763  PSI


       HEIGHT     384.00    LENGTH      144.00

     DYNAMIC CONCRETE STRENGTH      5000.00
     DYNAMIC STEEL STRESS          48000.00
     THICKNESS CONCRETE  INCHES      24.0000
     THICKNESS OF SAND   INCHES      48.0000
     THETA ALLOWABLE     DEGREES     12.0000
```

2

Figure 4. Continued.

```
AREA VERT TOP STEEL/FT          1.5800  COVER    2.0000
AREA VERT BOT STEEL/FT          1.5800  COVER    2.0000
AREA HORIZ TOP STEEL/FT         1.5800  COVER    3.0000
AREA HORIZ BOT STEEL/FT         1.5600  COVER    3.0000

CONCRETE MODULUS PSI               3644146
RATIO MOD STEEL/CONCRETE          7.96
GROSS MOMENT INERTIA           1152.00
AVE CRACKED MOM INERTIA         332.26
AVE MOMENT INERTIA              742.13
AVERAGE PERCENT STEEL           .0061
D FACTOR MU=1/6                       2781771691
D FACTOR  MU= 0.3                    2971910372


ALLOW SHEAR UNREINFORCED WEB    115.16  PSI         2475.99 LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT          720.00  PSI        15480.00  LBS/IN WIDTH
UNREINFORCED CONCRETE  THETA LE 2 DEG

POSITIVE VERTICAL MOMENT   126400.00
NEGATIVE VERTICAL MOMENT   126400.00
POSITIVE HORIZONTAL MOMENT   113760.00
NEGATIVE HORIZONTAL MOMENT   113760.00


SUPPORT ON  3 SIDES

YIELD LINE  Y  ABOVE FLOOR

LOCATION YIELD LINE LENGTH       72.00
LOCATION YIELD LINE HEIGHT      111.37
ULTIMATE LOAD CAPACITY  RU   101.9133
HORIZ SHEAR LOAD AT SUPPORT          6592.36  LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT           6809.89  LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT      217.36  PSI
VERT SHEARAT DIST FROM SUPPORT        243.92  PSI
ALLOWABLE MAX DEFLECTION      14.8890

SHEAR CAPACITY EXCEEDED


LOAD MASS FACTOR                  .6985
MASS CONCRETE ONLY              3766.44
```

```
LOCATION YIELD LINE LENGTH
LOCATION YIELD LINE HEIGHT         111.37
ULTIMATE LOAD CAPACITY  RU     101.9133
HORIZ SHEAR LOAD AT SUPPORT           6592.36   LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT            6809.89   LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT       217.36   PSI
VERT SHEARAT DIST FROM SUPPORT         243.92   PSI
ALLOWABLE MAX DEFLECTION       14.8890

SHEAR CAPACITY EXCEEDED


LOAD MASS FACTOR                      .6985
MASS CONCRETE ONLY                  3766.44


FIRST YIELD POINT AT PT2
ELASTIC  LIMIT  RE PSI                65.66
ELASTIC DEFLECTION  XE               .0702

SECOND YIELD AT PT 1
ELASTO PLASTIC LIMIT               76.66
ELASTO-PLASTIC DEFLECTION          .0943
ULTIMATE RESISTANCE               101.91
PLASTIC DEFLECTION                 .1497


ULTIMATE RESISTANCE RU       101.91
ELASTIC DEFLECTION LIMIT  XE      .1234
STIFFNESS  KE                     825.77


NATURAL PERIOD               17.323021
IMPULSE CAPACITY ONE WALL       4364.52
SCALLED IMPULSE CAPACITY         645.01
SCALED SAND THICKNESS             .5911
SCALED CONCRETE THICKNESS         .2956
```

2

OPTIONS 0 or 1: Optimum | P or I* | A_s or D | I Grid | Opening | Door Pr

CARD	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
1	Heading: Test Case, Example 2							
	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 72 73 74 75 76 77 78 79 80
	W (lb)	Expo No.	l/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (^oC)	Altitude (kft)	Effective Impulse
2	650	1.	0.					
	R_a (ft)/I (psi-ms)*	H (ft)	L (ft)	h (ft)/P_o (psi)*	l (ft)/t_o (ms)*	Cell Vol	Vent Area	F R L R
3	8.	32.	15.	16.	7.5	0.		1 0 1 1
	F_{dc} (psi)	F_{dy} (psi)	T_c (in.)	Theta (deg)	N Side	t Sand	BL Lacing	SL Lacing
4	5000.	48000.	24.	12.	3.			
	A_sVT (in.^{2}/ft)	A_sVB (in.^{2}/ft)	A_sHT (in.^{2}/ft)	A_sHB (in.^{2}/ft)	D'VT (in.)	D'VB (in.)	D'HT (in.)	D'HB (in.)
5a	1.58	1.58	1.58	1.58	2.	2.	3.	3.

Figure 5. Computer form, Example 2.

Figure 6. Computer results, Example 2.

```
 T E S T   C A S E,   E X A M P L E   2
TNT

EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  650.0
NUMBER EQWT    EFORM EXPLOSIVE COMPOSITION BY WEIGHT
             KCAL/G      C      H      N      O    AL
   1  1.000 -.078400   .370   .022   .185   .423 0.000

PAMB(PSIA)=  14.69        TAMB(C)=  20.00


SHOCK WAVE CALCULATION

INPUT PARAMETERS                                   CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)        =    650.0                ADJUSTED WT(LB TNT)  =    650.0
EXPLOSIVE NUMBER         =      1                  HE ENERGY FACTOR     =    1.000
L/D RATIO                = -0.                     CHARGE SHAPE FACTOR  =    1.000
CASE/CHARGE WT RATIO     = -0.                     CASE WEIGHT FACTOR   =    1.000
CHAMBER PRESSURE(PSIA)=    14.69                   PRESSURE SCALE FACTOR=    1.000
CHAMBER TEMP(C)          =   20.00                 DISTANCE SCALE FACTOR=    .1154
ALTITUDE (KFT)           = -0.                     TIME SCALE FACTOR    =    .1164
                                                   NORMAL REFL FACTOR   =    8.726

DESIRED DISTANCE(FT)    =    8.000
                (CM)    =    243.8

 TIME AFTER  TIME AFTER   INCIDENT    NORM REFL
 EXPLOSION   SHOCK ARR   OVERPRESS   OVERPRESS
  (MSEC)      (MSEC)       (PSI)       (PSI)
   .5229     0.            997.0        8699
   .8257       .3028       314.5        2744
   .9770       .4541       198.1        1729
   1.128       .6055       128.7        1123
   1.280       .7569       84.16       734.4
   1.431       .9083       54.24       473.2
   1.583       1.060       33.41       291.5
   1.734       1.211       18.57       162.0
   1.885       1.362       7.830       68.32
   2.037       1.514     0.           0.

IMPULSE (PSI.MSEC)--
```

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(CM) = 243.6

TIME AFTER EXPLOSION (MSEC)	TIME AFTER SHOCK ARR (MSEC)	INCIDENT OVERPRESS (PSI)	NORM REFL OVERPRESS (PSI)
.5229	0.	997.0	8699
.8257	.3028	314.5	2744
.9770	.4541	198.1	1729
1.128	.6055	128.7	1123
1.280	.7569	84.16	734.4
1.431	.9083	54.24	473.2
1.583	1.060	33.41	291.5
1.734	1.211	18.57	162.0
1.885	1.362	7.830	68.32
2.037	1.514	0.	0.

IMPULSE (PSI.MSEC)--
INCIDENT = 301.8
REFLECTED= 2633

.....CAUTION--CONTACT SURFACE HAS ARRIVED.
DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 94.0671E-03

DISTANCE OF CHARGE FROM BLAST WALL	FT.	8.00
CHARGE WEIGHT	LBS.	650.00
BLAST WALL HEIGHT	FT.	32.00
BLAST WALL LENGTH	FT.	15.00
HEIGHT OF CHARGE ABOVE GROUND	FT.	16.00
MIN. DIST. BETWEEN CHARGE + ADJ. WALL	FT.	7.50
REFLECTION CODE		1 0 1 1

TOTAL IMPULSE 3142.94 PSI-MS

DURATION OF LOAD 5.01601 MSEC

FICTITIOUS PEAK PRESSURE 1253.16399 PSI

Figure 6. (continued)

```
  HEIGHT      384.00    LENGTH      180.00

DYNAMIC CONCRETE STRENGTH     5000.00
DYNAMIC STEEL STRESS         48000.00
THICKNESS CONCRETE  INCHES    24.0000
THICKNESS OF SAND   INCHES     0.0000
THETA ALLOWABLE    DEGREES    12.0000


AREA VERT TOP STEEL/FT          1.5800  COVER    2.0000
AREA VERT BOT STEEL/FT          1.5800  COVER    2.0000
AREA HORIZ TOP STEEL/FT         1.5800  COVER    3.0000
AREA HORIZ BOT STEEL/FT         1.5800  COVER    3.0000

CONCRETE MODULUS PSI                3644146
RATIO MOD STEEL/CONCRETE          7.96
GROSS MOMENT INERTIA           1152.00
AVE CRACKED MOM INERTIA         332.26
AVE MOMENT INERTIA              742.13
AVERAGE PERCENT STEEL           .0061
D FACTOR MU=1/6                        2781771691
D FACTOR  MU= 0.3                      2971910372


ALLOW SHEAR UNREINFORCED WEB     115.16  PSI        2475.99 LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT           720.00  PSI       15480.00  LBS/IN WIDTH
UNREINFORCED CONCRETE  THETA LE 2 DEG

POSITIVE VERTICAL MOMENT   126400.00
NEGATIVE VERTICAL MOMENT   126400.00
POSITIVE HORIZONTAL MOMENT   113760.00
NEGATIVE HORIZONTAL MOMENT   113760.00


SUPPORT ON  3 SIDES

YIELD LINE   Y   ABOVE FLOOR

LOCATION YIELD LINE LENGTH       90.00
LOCATION YIELD LINE HEIGHT      137.89
ULTIMATE LOAD CAPACITY  RU     66.4754
HORIZ SHEAR LOAD AT SUPPORT          5221.07   LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT           5499.91   LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT      186.51   PSI
VERT SHEARAT DIST FROM SUPPORT        208.23   PSI
```

```
POSITIVE VERTICAL MOMENT    126400.00
NEGATIVE VERTICAL MOMENT    126400.00
POSITIVE HORIZONTAL MOMENT    113760.00
NEGATIVE HORIZONTAL MOMENT    113760.00


SUPPORT ON  3 SIDES

YIELD LINE  Y  ABOVE FLOOR

LOCATION YIELD LINE LENGTH         90.00
LOCATION YIELD LINE HEIGHT        137.89
ULTIMATE LOAD CAPACITY  RU     66.4754
HORIZ SHEAR LOAD AT SUPPORT             5221.07  LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT              5499.91  LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT          186.51  PSI
VERT SHEARAT DIST FROM SUPPORT            208.23  PSI
ALLOWABLE MAX DEFLECTION         18.6112

SHEAR CAPACITY EXCEEDED


LOAD MASS FACTOR                    .6934
MASS CONCRETE ONLY                3738.85


FIRST YIELD POINT AT PT2
ELASTIC  LIMIT  RE PSI               41.90
ELASTIC DEFLECTION  XE              .0947

SECOND YIELD AT PT 1
ELASTO PLASTIC LIMIT              50.67
ELASTO-PLASTIC DEFLECTION          .1406
ULTIMATE RESISTANCE               66.48
PLASTIC DEFLECTION                 .2242


ULTIMATE RESISTANCE RU         66.48
ELASTIC DEFLECTION LIMIT  XE        .1775
STIFFNESS  KE                     374.50
```


2

Figure 6. (continued)

MASS 3738.847
LOAD 1253.164
DURATION 5.016
RESISTANCE 66.475
STIFFNESS 374.496
GAS PRESSURE 0.00
DURATION 0.00

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
.266777	.3150	.0867	.0235	1186.5145	8.7986
.800330	.2683	.2426	.1338	1053.2154	50.1071
1.333884	.2283	.3745	.3174	919.9164	66.4754
1.867437	.1926	.4867	.5634	786.6174	66.4754
2.400990	.1570	.5800	.8617	653.3183	66.4754
2.934544	.1213	.6542	1.2022	520.0193	66.4754
3.468097	.0857	.7095	1.5746	386.7203	66.4754
4.001651	.0500	.7456	1.9689	253.4212	66.4754
4.535204	.0143	.7628	2.3749	120.1222	66.4754
5.068757	-.0178	.7614	2.7824	0.0000	66.4754
5.602311	-.0178	.7519	3.1849	0.0000	66.4754
6.135864	-.0178	.7424	3.5823	0.0000	66.4754
6.669418	-.0178	.7330	3.9746	0.0000	66.4754
7.202971	-.0178	.7235	4.3619	0.0000	66.4754
7.736524	-.0178	.7140	4.7441	0.0000	66.4754
8.270078	-.0178	.7045	5.1213	0.0000	66.4754
8.803631	-.0178	.6950	5.4934	0.0000	66.4754
9.337185	-.0178	.6855	5.8604	0.0000	66.4754
9.870738	-.0178	.6760	6.2224	0.0000	66.4754
10.404291	-.0178	.6666	6.5793	0.0000	66.4754
10.937845	-.0178	.6571	6.9312	0.0000	66.4754
11.471398	-.0178	.6476	7.2779	0.0000	66.4754
12.004952	-.0178	.6381	7.6197	0.0000	66.4754
12.538505	-.0178	.6286	7.9563	0.0000	66.4754
13.072058	-.0178	.6191	8.2879	0.0000	66.4754
13.605612	-.0178	.6096	8.6145	0.0000	66.4754
14.139165	-.0178	.6002	8.9360	0.0000	66.4754
14.672719	-.0178	.5907	9.2524	0.0000	66.4754
15.206272	-.0178	.5812	9.5637	0.0000	66.4754
15.739825	-.0178	.5717	9.8700	0.0000	66.4754
16.273379	-.0178	.5622	10.1713	0.0000	66.4754
16.806932	-.0178	.5527	10.4674	0.0000	66.4754
17.340486	-.0178	.5432	10.7585	0.0000	66.4754
17.874039	-.0178	.5337	11.0446	0.0000	66.4754
18.407592	-.0178	.5243	11.3256	0.0000	66.4754
18.941146	-.0178	.5148	11.6015	0.0000	66.4754
19.474699	-.0178	.5053	11.8724	0.0000	66.4754
[illegible]	-.0178	.4958	12.1382	0.0000	66.4754

14.139165	-.0178	.6002	8.9360	0.0000	66.4754
14.672719	-.0178	.5907	9.2524	0.0000	66.4754
15.206272	-.0178	.5812	9.5637	0.0000	66.4754
15.739825	-.0178	.5717	9.8700	0.0000	66.4754
16.273379	-.0178	.5622	10.1713	0.0000	66.4754
16.806932	-.0178	.5527	10.4674	0.0000	66.4754
17.340486	-.0178	.5432	10.7585	0.0000	66.4754
17.874039	-.0178	.5337	11.0446	0.0000	66.4754
18.407592	-.0178	.5243	11.3256	0.0000	66.4754
18.941146	-.0178	.5148	11.6015	0.0000	66.4754
19.474699	-.0178	.5053	11.8724	0.0000	66.4754
20.008253	-.0178	.4958	12.1382	0.0000	66.4754
20.541806	-.0178	.4863	12.3989	0.0000	66.4754
21.075359	-.0178	.4768	12.6546	0.0000	66.4754
21.608913	-.0178	.4673	12.9052	0.0000	66.4754
22.142466	-.0178	.4579	13.1508	0.0000	66.4754
22.676020	-.0178	.4484	13.3913	0.0000	66.4754
23.209573	-.0178	.4389	13.6267	0.0000	66.4754
23.743126	-.0178	.4294	13.8571	0.0000	66.4754
24.276680	-.0178	.4199	14.0824	0.0000	66.4754
24.810233	-.0178	.4104	14.3026	0.0000	66.4754
25.343787	-.0178	.4009	14.5178	0.0000	66.4754
25.877340	-.0178	.3915	14.7280	0.0000	66.4754
26.410893	-.0178	.3820	14.9330	0.0000	66.4754
26.944447	-.0178	.3725	15.1330	0.0000	66.4754
27.478000	-.0178	.3630	15.3280	0.0000	66.4754
28.011554	-.0178	.3535	15.5178	0.0000	66.4754
28.545107	-.0178	.3440	15.7027	0.0000	66.4754
29.078660	-.0178	.3345	15.8824	0.0000	66.4754
29.612214	-.0178	.3250	16.0571	0.0000	66.4754
30.145767	-.0178	.3156	16.2267	0.0000	66.4754
30.679321	-.0178	.3061	16.3913	0.0000	66.4754
31.212874	-.0178	.2966	16.5508	0.0000	66.4754
31.746427	-.0178	.2871	16.7053	0.0000	66.4754
32.279981	-.0178	.2776	16.8547	0.0000	66.4754
32.813534	-.0178	.2681	16.9990	0.0000	66.4754
33.347088	-.0178	.2586	17.1383	0.0000	66.4754
33.880641	-.0178	.2492	17.2725	0.0000	66.4754
34.414194	-.0178	.2397	17.4016	0.0000	66.4754
34.947748	-.0178	.2302	17.5257	0.0000	66.4754
35.481301	-.0178	.2207	17.6447	0.0000	66.4754
36.014855	-.0178	.2112	17.7587	0.0000	66.4754
36.548408	-.0178	.2017	17.8676	0.0000	66.4754
37.081961	-.0178	.1922	17.9714	0.0000	66.4754
37.615515	-.0178	.1828	18.0702	0.0000	66.4754
38.149068	-.0178	.1733	18.1639	0.0000	66.4754
38.682622	-.0178	.1638	18.2525	0.0000	66.4754
39.216175	-.0178	.1543	18.3361	0.0000	66.4754
39.749728	-.0178	.1448	18.4147	0.0000	66.4754
40.283282	-.0178	.1353	18.4881	0.0000	66.4754
40.816835	-.0178	.1258	18.5565	0.0000	66.4754
41.350389	-.0178	.1163	18.6199	0.0000	66.4754
41.883942	-.0178	.1069	18.6782	0.0000	66.4754
42.417495	-.0178	.0974	18.7314	0.0000	66.4754
42.951049	-.0178	.0879	18.7795	0.0000	66.4754

34.414194	-.0178	.2397	17.4016	0.0000	66.4754
34.947748	-.0178	.2302	17.5257	0.0000	66.4754
35.481301	-.0178	.2207	17.6447	0.0000	66.4754
36.014855	-.0178	.2112	17.7587	0.0000	66.4754
36.548408	-.0178	.2017	17.8676	0.0000	66.4754
37.081961	-.0178	.1922	17.9714	0.0000	66.4754
37.615515	-.0178	.1828	18.0702	0.0000	66.4754
38.149068	-.0178	.1733	18.1639	0.0000	66.4754
38.682622	-.0178	.1638	18.2525	0.0000	66.4754
39.216175	-.0178	.1543	18.3361	0.0000	66.4754
39.749728	-.0178	.1448	18.4147	0.0000	66.4754
40.283282	-.0178	.1353	18.4881	0.0000	66.4754
40.816835	-.0178	.1258	18.5565	0.0000	66.4754
41.350389	-.0178	.1163	18.6199	0.0000	66.4754
41.883942	-.0178	.1069	18.6782	0.0000	66.4754
42.417495	-.0178	.0974	18.7314	0.0000	66.4754
42.951049	-.0178	.0879	18.7795	0.0000	66.4754
43.484602	-.0178	.0784	18.8226	0.0000	66.4754
44.018156	-.0178	.0689	18.8607	0.0000	66.4754
44.551709	-.0178	.0594	18.8936	0.0000	66.4754
45.085262	-.0178	.0499	18.9216	0.0000	66.4754
45.618816	-.0178	.0405	18.9444	0.0000	66.4754
46.152369	-.0178	.0310	18.9622	0.0000	66.4754
46.685923	-.0178	.0215	18.9749	0.0000	66.4754
47.219476	-.0178	.0120	18.9826	0.0000	66.4754
47.753029	-.0178	.0025	18.9852	0.0000	66.4754

NATURAL PERIOD 19.852943

MAXIMUM DEFLECTION 18.985192

TIME TO MAXIMUM DEFLECTION 47.753029

DURATION/NATURAL PERIOD .252658

LOAD/RESISTANCE 18.851540

ELASTIC DEFLECTION LIMIT .177506

MAX FRAGMENT SPALL VELOCITY FT/SEC 63.688186

WALL COLLAPSES
AVERAGE SCAB VELC TY 9.70
MAX SCAB VELOCITY 48.48

3

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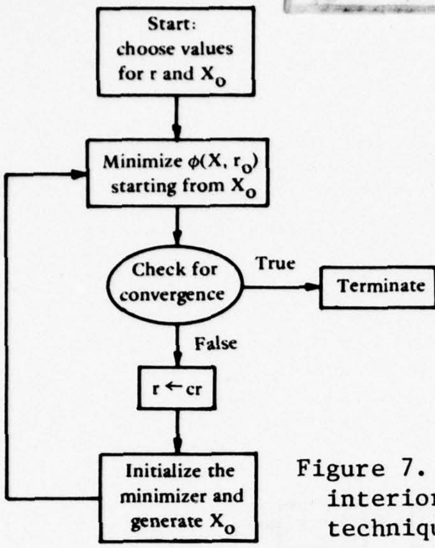

Figure 7. Logic diagram for interior penalty function technique.

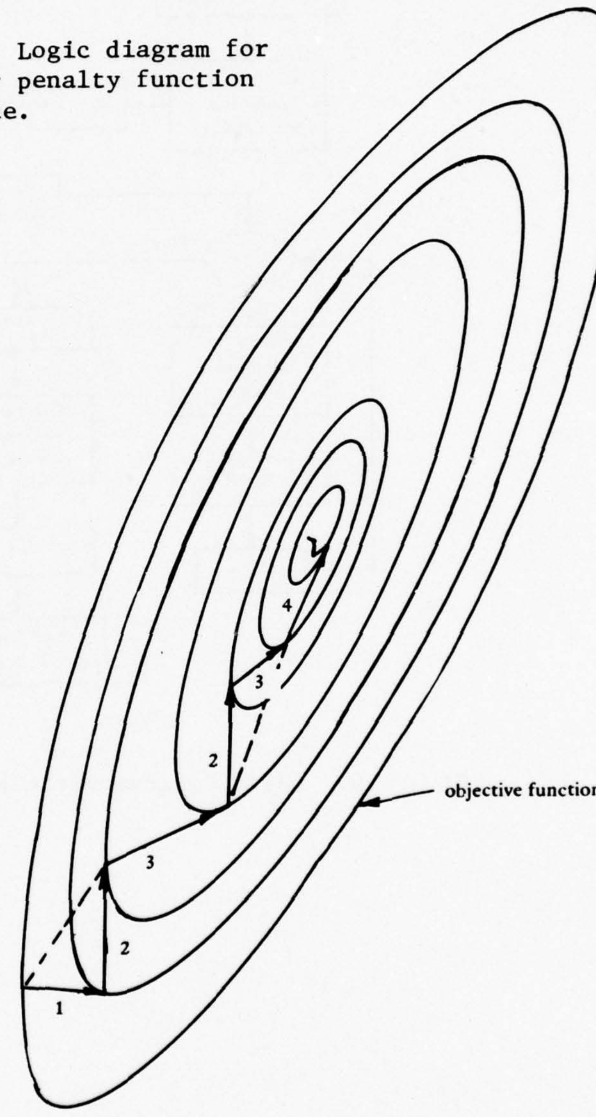

Figure 8. Step process, Powell method.

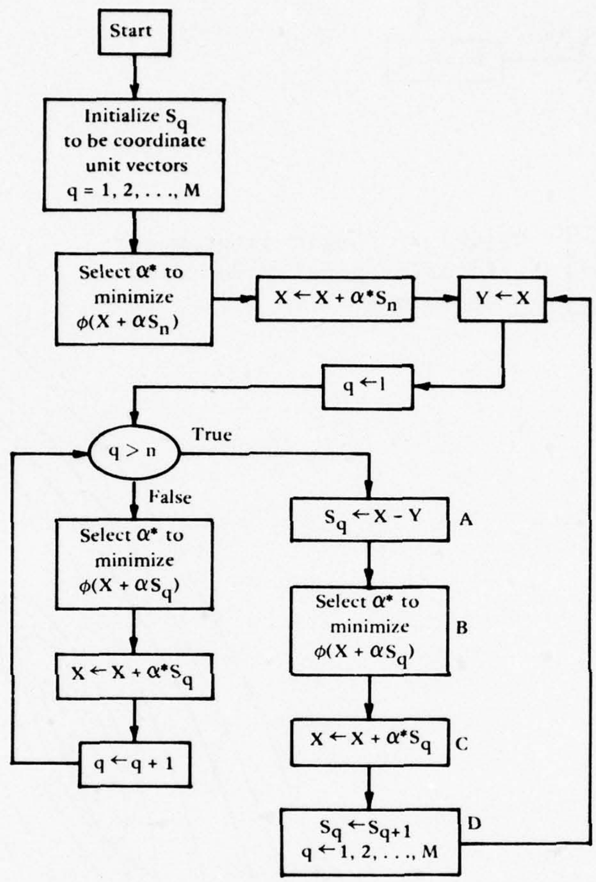

Figure 9. Logic diagram for minimization of $\phi(X)$.

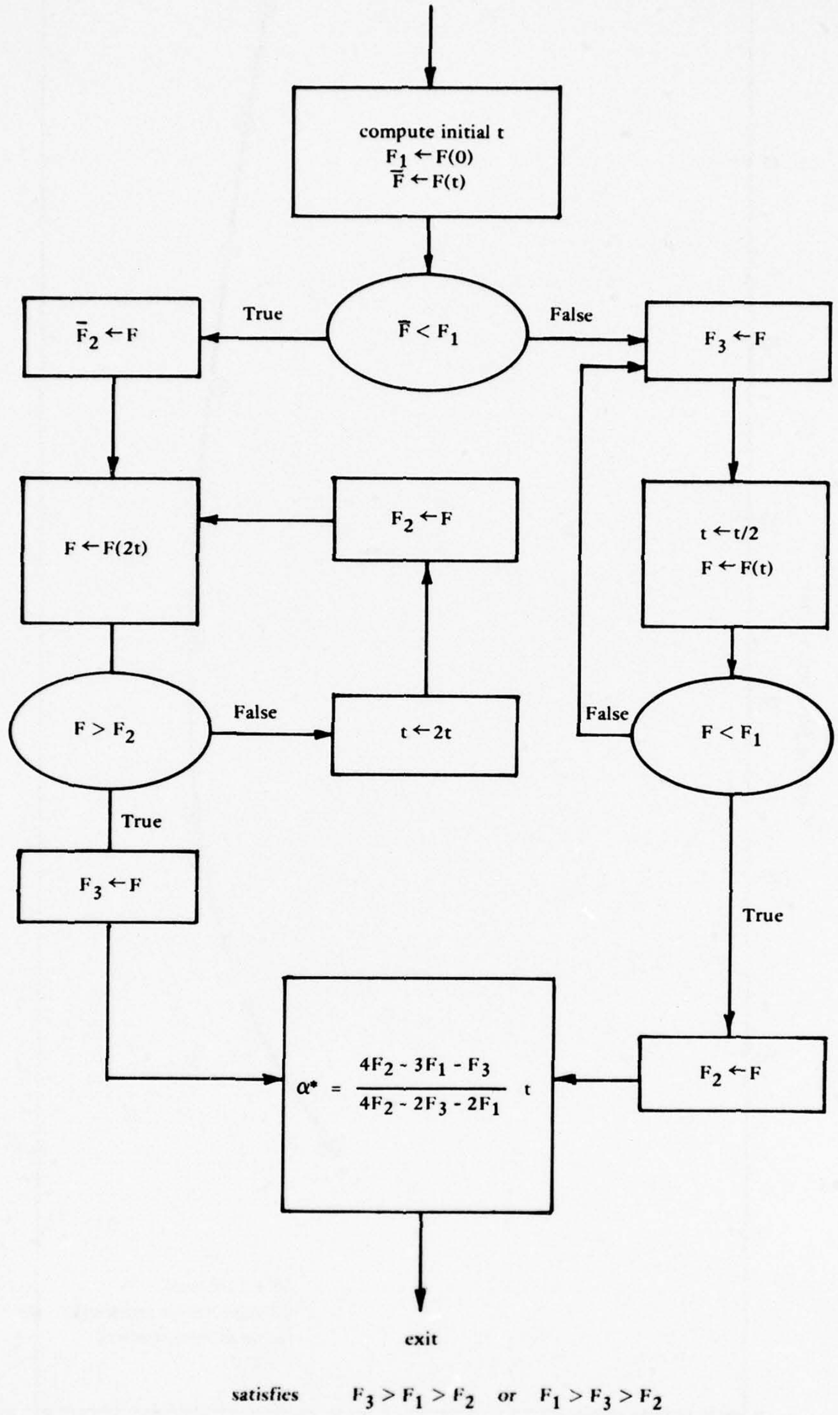

Figure 10. One-dimensional minimization algorithm.

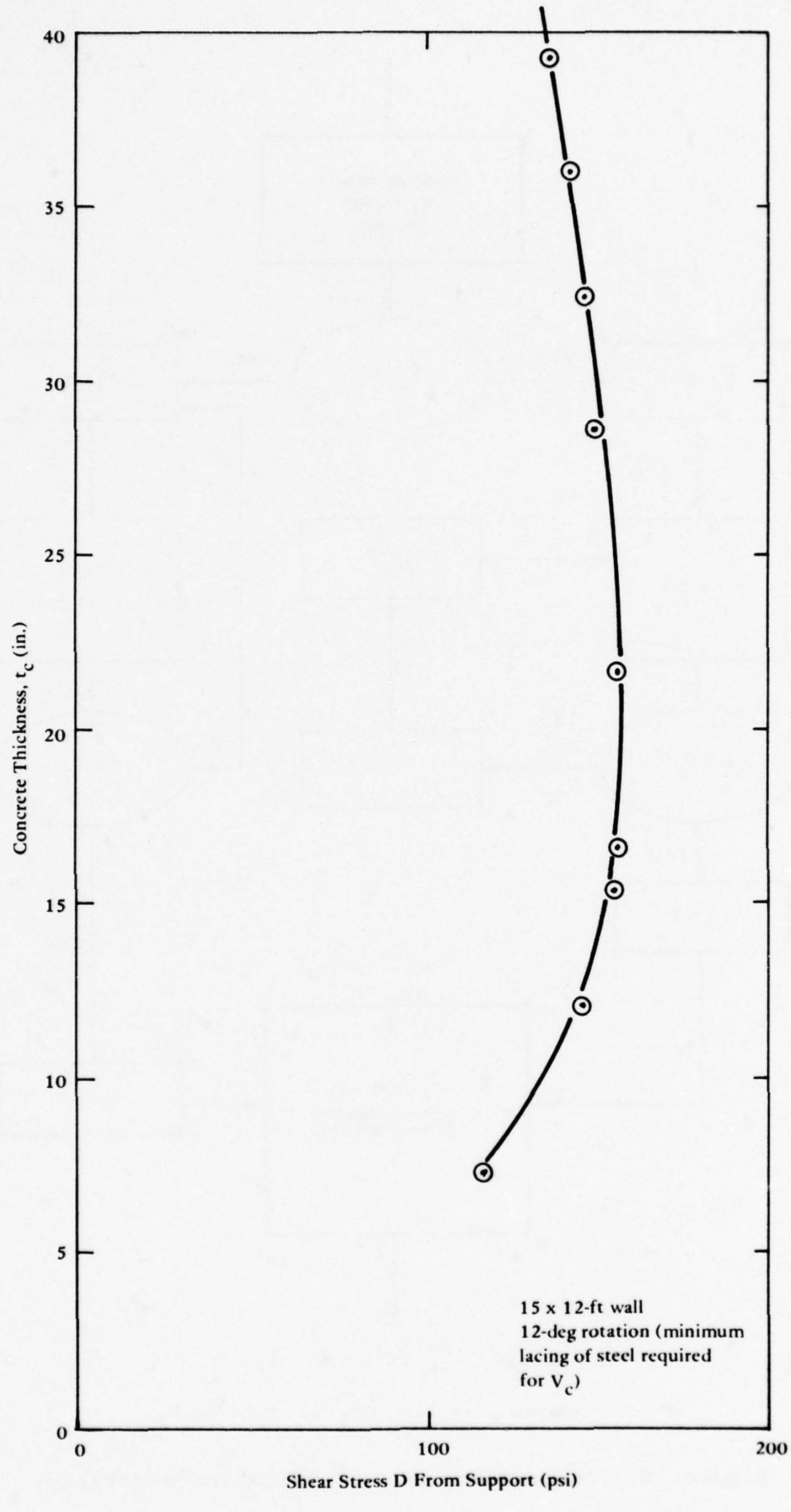

Figure 11. Shear stress as a function of thickness.

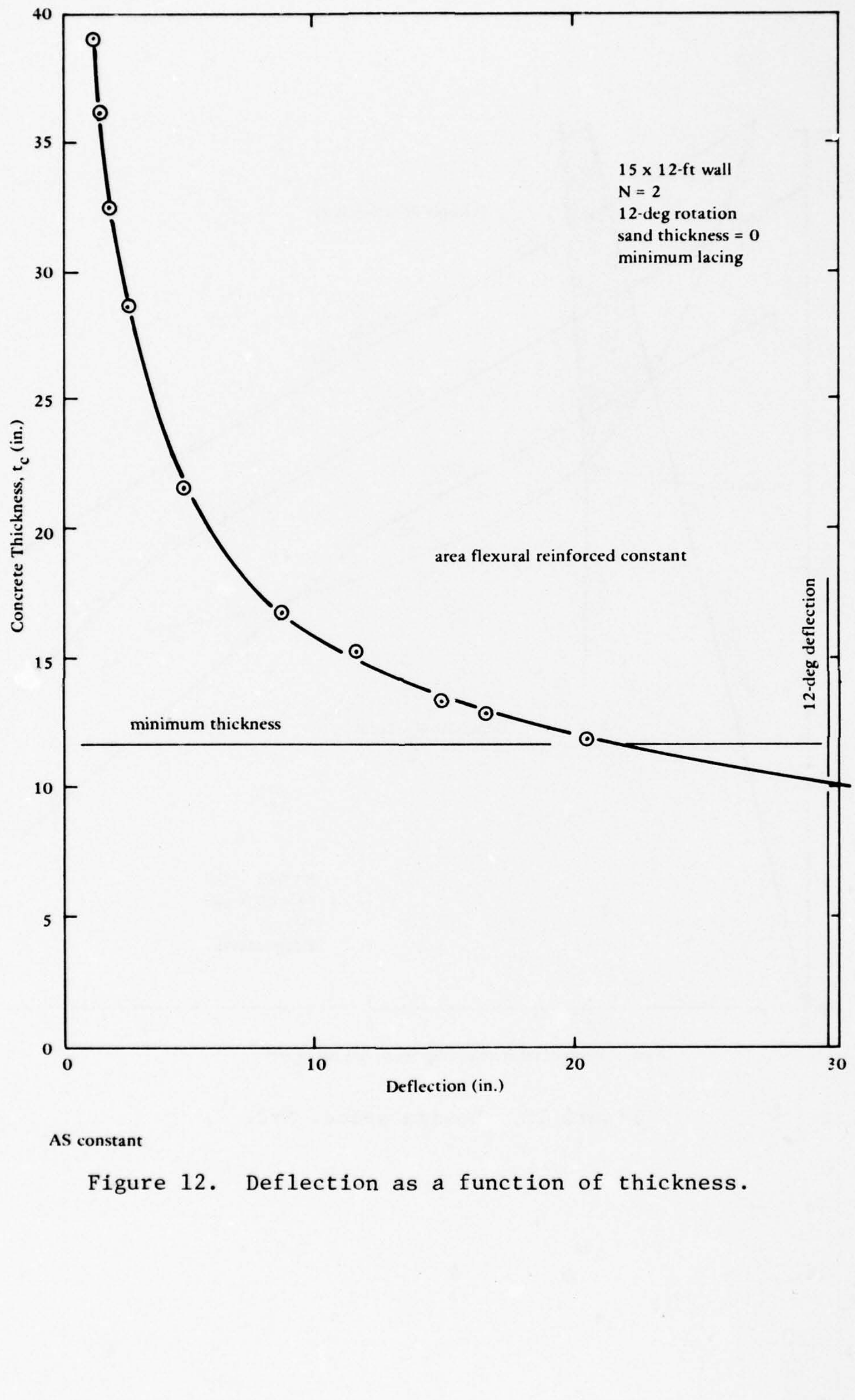

Figure 12. Deflection as a function of thickness.

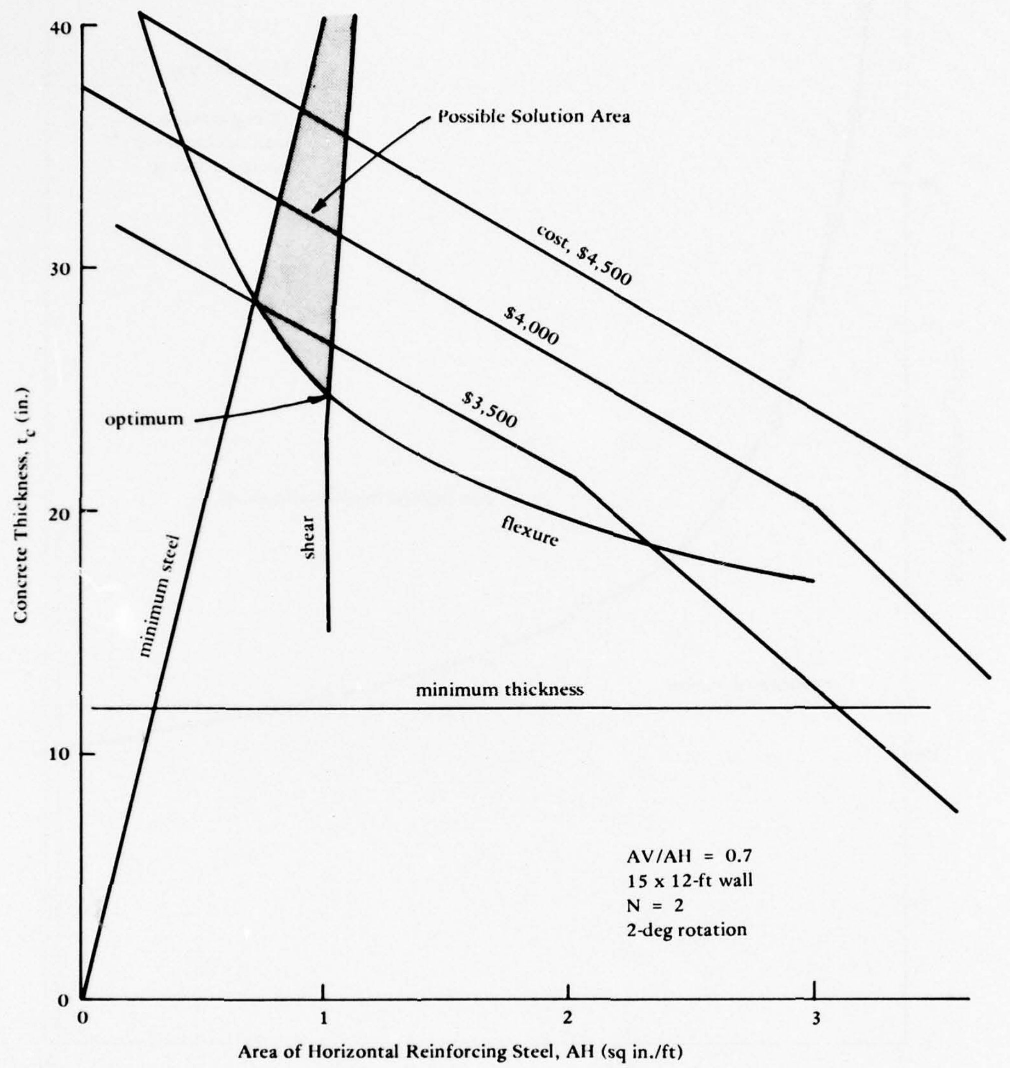

Figure 13. Design space, N=2.

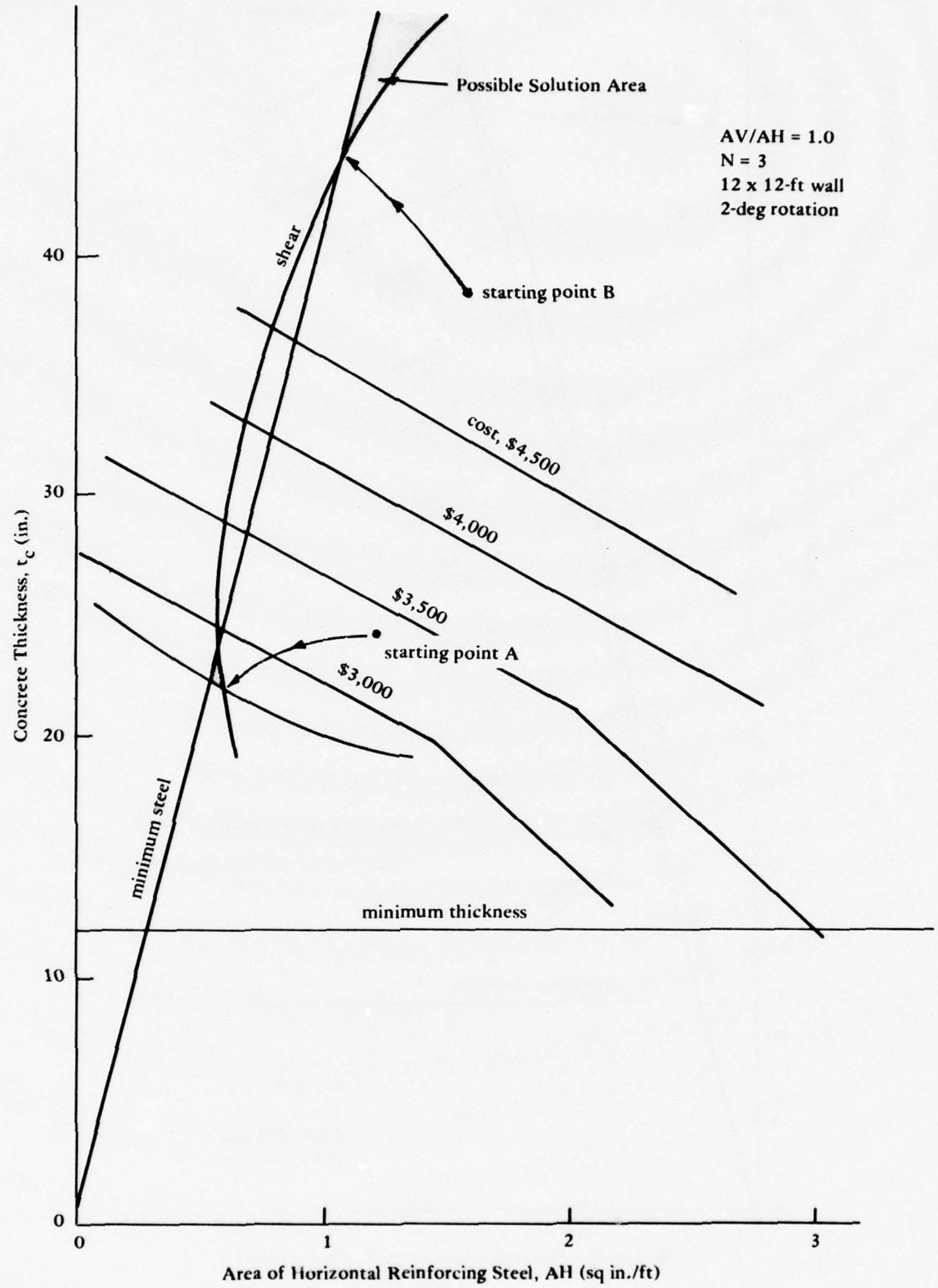

Figure 14. Design space, N=3.

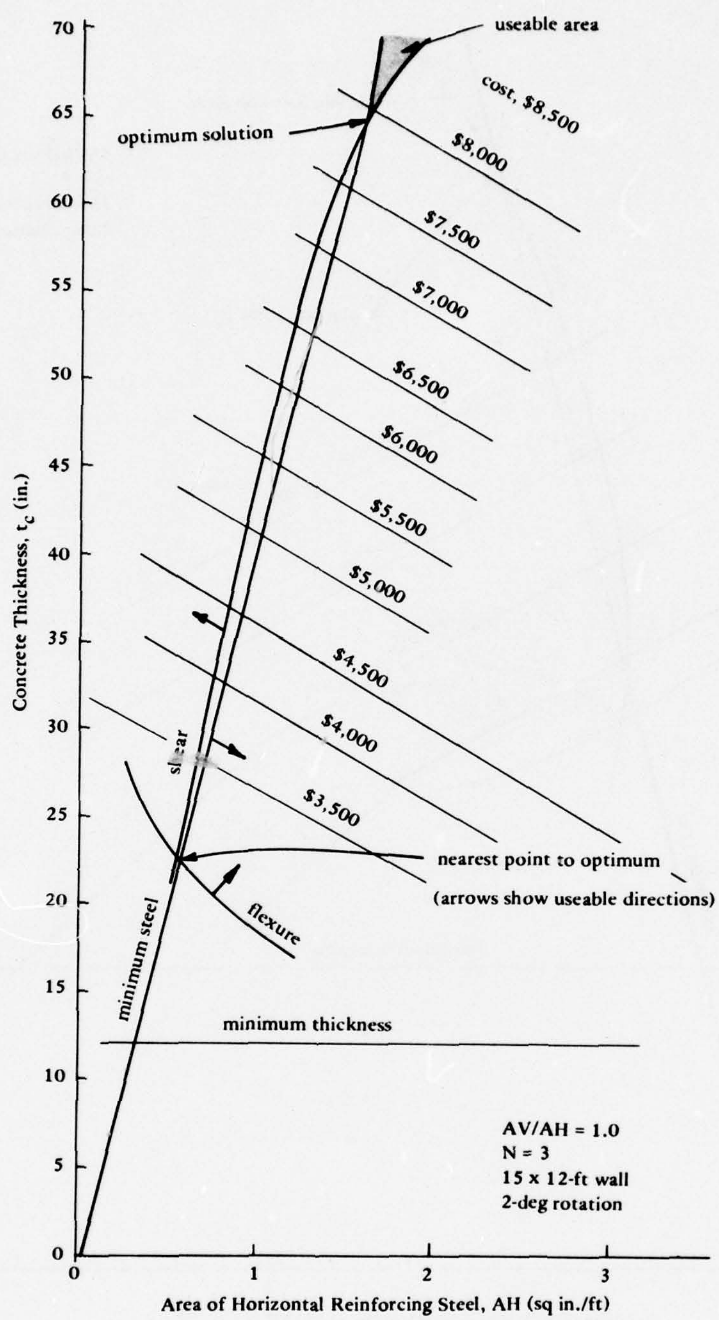

Figure 15. Revised design space, N=3.

Appendix

EXAMPLE PROBLEMS

This Appendix presents several example problems showing the use of optimization. Test Case A-1 is shown in Figures A-1 and A-2. The input estimated 24-inch-thick concrete and 1.58 sq in. of steel per foot with a cost of $8,199. The final design resulted in a 12-inch-thick concrete section with vertical steel 0.41 sq in./ft and horizontal steel 1.23 sq in./ft costing $4,958.

Input for Test Cast A-2 is shown in Figure A-3. The preliminary cost was $3,433; however, the shear capacity of the proposed section was inadequate. The final design was a 23.6-inch-thick concrete section with 0.86 sq in./ft of vertical steel and 0.98 sq in./ft of horizontal steel costing $3,192, as shown in Figure A-4.

OPTIONS 0 or 1

Optimum	P or I*	A_s or D	I Grid	Opening	Door Pr
1			1		

CARD	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
1	Heading: Test Case, Example A-1							
	W (lb)	Expl No.	l/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (^oC)	Altitude (kft)	Effective Impulse
2	210	1						1.0
	R_a (ft)/I (psi-ms)*	H (ft)	L (ft)	h (ft)/P_o (psi)*	I (ft)/t_o (ms)*	Cell Vol	Vent Area	F R L R
3	3	32	12	6	3			1 0 1 1
	F_{dc} (psi)	F_{dy} (psi)	T_c (in.)	Theta (deg)	N Side	t Sand	BL Lacing	SL Lacing
4	5000.	48000.	24	12.	3.	4.	6.	6.
	A_sVT (in.^{2}/ft)	A_sVB (in.^{2}/ft)	A_sHT (in.^{2}/ft)	A_sHB (in.^{2}/ft)	D'VT (in.)	D'VB (in.)	D'HT (in.)	D'HB (in.)
5a	1.58	1.58	1.58	1.58	2	2	3	3

Figure A-1. Input for Test Case A-1.

Figure A-2. Results for Test Case A-1.

```
 T E S T  C A S E,  E X A M P L E  A - 1
TNT

EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  210.0
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G      C     H     N     O    AL
   1  1.000 -.078400  .370  .022  .185  .423 0.000

PAMB(PSIA)=  14.69        TAMB(C)=  20.00


SHOCK WAVE CALCULATION

INPUT PARAMETERS                            CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)        =   210.0          ADJUSTED WT(LB TNT)  =   210.0
EXPLOSIVE NUMBER         =     1            HE ENERGY FACTOR     =   1.000
L/D RATIO                = -0.              CHARGE SHAPE FACTOR  =   1.000
CASE/CHARGE WT RATIO     = -0.              CASE WEIGHT FACTOR   =   1.000
CHAMBER PRESSURE(PSIA)=     14.69           PRESSURE SCALE FACTOR=   1.000
CHAMBER TEMP(C)          =   20.00          DISTANCE SCALE FACTOR=   .1682
ALTITUDE (KFT)           = -0.              TIME SCALE FACTOR    =   .1697
                                            NORMAL REFL FACTOR   =   10.21

DESIRED DISTANCE(FT)   =   3.000
                (CM)   =   91.44

 TIME AFTER  TIME AFTER   INCIDENT   NORM REFL
 EXPLOSION   SHOCK ARR    OVERPRESS  OVERPRESS
  (MSEC)      (MSEC)       (PSI)      (PSI)
   .1276     0.            2362     24.1276E+03
   .2526      .1250        745.1       7610
   .3151      .1875        469.5       4795
   .3776      .2500        304.9       3114
   .4401      .3125        199.4       2037
   .5026      .3750        128.5       1313
   .5651      .4375        79.16      808.5
   .6276      .5000        43.99      449.3
   .6901      .5625        18.55      189.5
   .7526      .6250       0.          0.

IMPULSE (PSI,MSEC)--
```

.2526	.1250	745.1	7610
.3151	.1875	469.5	4795
.3776	.2500	304.9	3114
.4401	.3125	199.4	2037
.5026	.3750	128.5	1313
.5651	.4375	79.16	808.5
.6276	.5000	43.99	449.3
.6901	.5625	18.55	189.5
.7526	.6250	0.	0.

IMPULSE (PSI.MSEC)--
INCIDENT = 295.2
REFLECTED= 3015

.....CAUTION--CONTACT SURFACE HAS ARRIVED.
DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 14.5548E-03

DISTANCE OF CHARGE FROM BLAST WALL	FT.	3.00
CHARGE WEIGHT	LBS.	210.00
BLAST WALL HEIGHT	FT.	32.00
BLAST WALL LENGTH	FT.	12.00
HEIGHT OF CHARGE ABOVE GROUND	FT.	6.00
MIN. DIST. BETWEEN CHARGE + ADJ. WALL	FT.	3.00
REFLECTION CODE		1 0 1 1

THE REFLECTED IMPULSE (PSI-MSEC) AT EACH GRID POINT ON THE BLAST WALL IS...
(MACH REFLECTIONS NOT INCLUDED)

J= 17	665.2	674.0	688.1	715.5	739.6
J= 16	717.3	738.3	756.3	787.1	821.2
J= 15	779.7	817.2	840.1	874.7	921.9
J= 14	857.9	883.5	941.1	972.3	1008
J= 13	954.6	983.0	1062	1075	1124
J= 12	1099	1128	1121	1201	1254
J= 11	1298	1331	1268.	1387	1454
J= 10	1548	1500	1436	1296	1747
J= 9	1922	1772	1380	1419	1577
J= 8	2631	2130	1487	1527	1748
J= 7	3948	1852	1587	1606	2334

J= 16	717.3	738.3	756.3	787.1	821.2
J= 15	779.7	817.2	840.1	874.7	921.9
J= 14	857.9	883.5	941.1	972.3	1008
J= 13	954.6	983.0	1062	1075	1124
J= 12	1099	1128	1121	1201	1254
J= 11	1296	1331	1268.	1387	1454
J= 10	1548	1500	1436	1296	1747
J= 9	1922	1772	1380	1419	1577
J= 8	2631	2130	1487	1527	1748
J= 7	3948	1852	1587	1606	2334
J= 6	6701	2056	1664	1663	2498
J= 5	1.1837E+04	2180	1718	1707	2543
J= 4	5780	2270	1805	1794	2592
J= 3	1.2150E+04	2484	2031	1993	2773
J= 2	7463	2817	2425	2310	2963
J= 1	7263	5214	4902	2780	3745
I=	1	2	3	4	5

TOTAL IMPULSE 1738.06

TOTAL IMPULSE 1885.68 PSI-MS

DURATION OF LOAD 15.99917 MSEC

FICTITIOUS PEAK PRESSURE 235.72224 PSI

3

Figure A-2. Continued

```
HEIGHT      384.00     LENGTH      144.00

DYNAMIC CONCRETE STRENGTH      5000.00
DYNAMIC STEEL STRESS          48000.00
THICKNESS CONCRETE  INCHES      12.2751
THICKNESS OF SAND   INCHES      48.0000
THETA ALLOWABLE    DEGREES      12.0000

AREA VERT TOP STEEL/FT            .4172  COVER    2.0000
AREA VERT BOT STEEL/FT            .4172  COVER    2.0000
AREA HORIZ TOP STEEL/FT          1.2316  COVER    3.0000
AREA HORIZ BOT STEEL/FT          1.2316  COVER    3.0000

CONCRETE MODULUS PSI                 3644146
RATIO MOD STEEL/CONCRETE          7.96
GROSS MOMENT INERTIA            154.13
AVE CRACKED MOM INERTIA          31.33
AVE MOMENT INERTIA               92.73
AVERAGE PERCENT STEEL            .0072
D FACTOR MU=1/6                          347585935
D FACTOR  MU= 0.3                       371344007

ALLOW SHEAR UNREINFORCED WEB      117.49  PSI          1148.51 LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT            720.00  PSI          7038.09  LBS/IN WIDTH
UNREINFORCED CONC  TE  THETA LE 2 DEG

POSITIVE VERTICAL MOMENT      13809.47
NEGATIVE VERTICAL MOMENT      13809.47
POSITIVE HORIZONTAL MOMENT     30913.33
NEGATIVE HORIZONTAL MOMENT     30913.33

SUPPORT ON  3 SIDES

YIELD LINE  Y  ABOVE FLOOR

LOCATION YIELD LINE LENGTH        72.00
LOCATION YIELD LINE HEIGHT        72.00
ULTIMATE LOAD CAPACITY  RU      26.6405
```

```
POSITIVE VERTICAL MOMENT     13809.47
NEGATIVE VERTICAL MOMENT     13809.47
POSITIVE HORIZONTAL MOMENT     30913.33
NEGATIVE HORIZONTAL MOMENT     30913.33


SUPPORT ON  3 SIDES

YIELD LINE  Y  ABOVE FLOOR

LOCATION YIELD LINE LENGTH          72.00
LOCATION YIELD LINE HEIGHT          72.00
ULTIMATE LOAD CAPACITY  RU     26.6405
HORIZ SHEAR LOAD AT SUPPORT             1794.37  LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT              1150.83  LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT     159.20  PSI
VERT SHEARAT DIST FROM SUPPORT        98.65  PSI
ALLOWABLE MAX DEFLECTION       14.8885

SHEAR CAPACITY EXCEEDED

    BAR SPACING WIDTH                    6.00
    BAR SPACING LENGTH                   6.00
    BAR VERTICAL HEIGHT                  9.28
    ANGLE ALPHA                         64.88
    EXCESS SHEAR STRESS                117.49
    STEEL  STRESS                    48000.00
    AREA STEEL LACING REQ                 .08
    BAR NUMBER LACING REQ                3.00


LOAD MASS FACTOR                     .7057
MASS CONCRETE ONLY                 1946.17


FIRST YIELD POINT AT PT3
ELASTIC  LIMIT  RE PSI               13.15
ELASTIC DEFLECTION  XE               .1124

SECOND YIELD AT PT 2
ELASTO PLASTIC LIMIT               16.28
ELASTO-PLASTIC DEFLECTION          .1675
ULTIMATE RESISTANCE               26.64
PLASTIC DEFLECTION                 .3493


ULTIMATE RESISTANCE RU       26.64
ELASTIC DEFLECTION LIMIT  XE       .2893
STIFFNESS  KE                      92.07
```

```
ELASTIC DEFLECTION  XE            .1124

SECOND YIELD AT PT 2
ELASTO PLASTIC LIMIT             16.28
ELASTO-PLASTIC DEFLECTION         .1675
ULTIMATE RESISTANCE              26.64
PLASTIC DEFLECTION                .3493


ULTIMATE RESISTANCE RU       26.64
ELASTIC DEFLECTION LIMIT  XE      .2893
STIFFNESS  KE                    92.07


NATURAL PERIOD              43.840488
IMPULSE CAPACITY ONE WALL      1885.68
SCALLED IMPULSE CAPACITY        317.30
SCALED SAND THICKNESS             .0731
SCALED CONCRETE THICKNESS         .1721
   TOTAL COST      4957.63
  COUNT     1030.00
```

3

OPTIONS 0 or 1

CARD	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
							Optimum: 1	P or I*: 1; A_s or D; I Grid; Opening; Door Pr
1	Heading: Test Case, Example A-2							
	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 72 73 74 75 76 77 78 79 80
	W (lb)	Expo No.	I/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (^oC)	Altitude (kft)	Effective Impulse
2	20.	1.						
	R_a (ft)/I (psi-ms)*	H (ft)	L (ft)	h (ft)/P_o (psi)*	I (ft)/t_o (ms)*	Cell Vol	Vent Area	F R L R
3	1,000.	15.	12.	200.	10.			1 1
	F_{dc} (psi)	F_{dy} (psi)	T_c (in.)	Theta (deg)	N Side	t Sand	BL Lacing	SL Lacing
4	5000.	48000.	24.	2.	2.	0		
	A_sVT (in.^{2}/ft)	A_sVB (in.^{2}/ft)	A_sHT (in.^{2}/ft)	A_sHB (in.^{2}/ft)	D'VT (in.)	D'VB (in.)	D'HT (in.)	D'HB (in.)
5a	1.185	1.185	1.185	1.185	2.	2.	2.	2.

Figure A-3. Input for Test Case A-2.

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Figure A-4. Results of Test Case A-2.

```
    HEIGHT      180.00     LENGTH       144.00

DYNAMIC CONCRETE STRENGTH       5000.00
DYNAMIC STEEL STRESS           48000.00
THICKNESS CONCRETE   INCHES     23.5804
THICKNESS OF SAND    INCHES      0.0000
THETA ALLOWABLE     DEGREES      2.0000


AREA VERT TOP STEEL/FT             .8631   COVER     2.0000
AREA VERT BOT STEEL/FT             .8631   COVER     2.0000
AREA HORIZ TOP STEEL/FT            .9768   COVER     2.0000
AREA HORIZ BOT STEEL/FT            .9768   COVER     2.0000

CONCRETE MODULUS PSI                  3644146
RATIO MOD STEEL/CONCRETE         7.96
GROSS MOMENT INERTIA          1092.62
AVE CRACKED MOM INERTIA        211.43
AVE MOMENT INERTIA             652.03
AVERAGE PERCENT STEEL            .0036
D FACTOR MU=1/6                            2444021713
D FACTOR  MU= 0.3                         2611074626


ALLOW SHEAR UNREINFORCED WEB     109.69   PSI           2367.15 LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT           720.00   PSI          15537.86  LBS/IN WIDTH
UNREINFORCED CONCRETE  THETA LE 2 DEG

POSITIVE VERTICAL MOMENT     67596.85
NEGATIVE VERTICAL MOMENT     67596.85
POSITIVE HORIZONTAL MOMENT     76500.64
NEGATIVE HORIZONTAL MOMENT     76500.64
```

```
ALLOW SHEAR UNREINFORCED WEB      109.69   PSI          2367.15 LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT            720.00   PSI         15537.86  LBS/IN WIDTH
UNREINFORCED CONCRETE   THETA LE 2 DEG

POSITIVE VERTICAL MOMENT     67596.85
NEGATIVE VERTICAL MOMENT     67596.85
POSITIVE HORIZONTAL MOMENT     76500.64
NEGATIVE HORIZONTAL MOMENT     76500.64


SUPPORT ON  2 SIDES

YIELD LINE  Y  ABOVE FLOOR

LOCATION YIELD LINE LENGTH        144.00
LOCATION YIELD LINE HEIGHT        152.27
ULTIMATE LOAD CAPACITY  RU      29.1558
HORIZ SHEAR LOAD AT SUPPORT           2820.29  LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT            2663.65  LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT       109.69  PSI
VERT SHEARAT DIST FROM SUPPORT         102.55  PSI
ALLOWABLE MAX DEFLECTION         5.0329


LOAD MASS FACTOR                   .5958
MASS CONCRETE ONLY               3156.54



FIRST YIELD POINT AT PT2
ELASTIC  LIMIT  RE PSI              11.56
ELASTIC DEFLECTION  XE             .0887
ULTIMATE RESISTANCE              29.16
PLASTIC DEFLECTION                 .3563



ULTIMATE RESISTANCE RU        29.16
ELASTIC DEFLECTION LIMIT  XE        .3037
STIFFNESS  KE                     95.99

 MASS        3156.536
LOAD         200.000
DURATION      10.000
RESISTANCE     29.156
STIFFNESS    95.989
 GAS PRESSURE        0.00
 DURATION       0.00
```

2

Figure A-4. Continued

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
.202070	.0620	.0127	.0026	195.9586	.2470
.606211	.0591	.0371	.0152	187.8758	1.4561
1.010352	.0558	.0604	.0373	179.7930	3.5787
1.414492	.0523	.0822	.0684	171.7102	6.5630
1.818633	.0486	.1026	.1079	163.6273	10.3531
2.222774	.0446	.1214	.1551	155.5445	14.8890
2.626914	.0403	.1386	.2095	147.4617	20.1072
3.031055	.0359	.1540	.2702	139.3789	25.9409
3.435196	.0324	.1677	.3367	131.2961	29.1558
3.839336	.0298	.1803	.4084	123.2133	29.1558
4.243477	.0272	.1918	.4848	115.1305	29.1558
4.647618	.0247	.2023	.5655	107.0476	29.1558
5.051758	.0221	.2117	.6502	98.9648	29.1558
5.455899	.0196	.2202	.7384	90.8820	29.1558
5.860040	.0170	.2276	.8296	82.7992	29.1558
6.264180	.0144	.2339	.9236	74.7164	29.1558
6.668321	.0119	.2392	1.0198	66.6336	29.1558
7.072461	.0093	.2435	1.1178	58.5508	29.1558
7.476602	.0068	.2467	1.2172	50.4680	29.1558
7.880743	.0042	.2490	1.3177	42.3851	29.1558
8.284883	.0016	.2501	1.4187	34.3023	29.1558
8.689024	-.0009	.2503	1.5199	26.2195	29.1558
9.093165	-.0035	.2494	1.6208	18.1367	29.1558
9.497305	-.0061	.2475	1.7210	10.0539	29.1558
9.901446	-.0086	.2445	1.8202	1.9711	29.1558
10.305587	-.0092	.2408	1.9179	0.0000	29.1558
10.709727	-.0092	.2371	2.0141	0.0000	29.1558
11.113868	-.0092	.2334	2.1088	0.0000	29.1558
11.518009	-.0092	.2296	2.2020	0.0000	29.1558
11.922149	-.0092	.2259	2.2936	0.0000	29.1558
12.326290	-.0092	.2222	2.3838	0.0000	29.1558
12.730431	-.0092	.2184	2.4724	0.0000	29.1558
13.134571	-.0092	.2147	2.5596	0.0000	29.1558
13.538712	-.0092	.2110	2.6452	0.0000	29.1558
13.942853	-.0092	.2072	2.7293	0.0000	29.1558
14.346993	-.0092	.2035	2.8120	0.0000	29.1558
14.751134	-.0092	.1998	2.8931	0.0000	29.1558
15.155275	-.0092	.1960	2.9727	0.0000	29.1558
15.559415	-.0092	.1923	3.0508	0.0000	29.1558
15.963556	-.0092	.1886	3.1273	0.0000	29.1558
16.367697	-.0092	.1848	3.2024	0.0000	29.1558
16.771837	-.0092	.1811	3.2760	0.0000	29.1558
17.175978	-.0092	.1774	3.3480	0.0000	29.1558
17.580119	-.0092	.1736	3.4186	0.0000	29.1558
17.984259	-.0092	.1699	3.4876	0.0000	29.1558

2

13.134571	-.0092	.2147	[illegible]	[illegible]	[illegible]
13.538712	-.0092	.2110	2.6452	0.0000	29.1558
13.942853	-.0092	.2072	2.7293	0.0000	29.1558
14.346993	-.0092	.2035	2.8120	0.0000	29.1558
14.751134	-.0092	.1998	2.8931	0.0000	29.1558
15.155275	-.0092	.1960	2.9727	0.0000	29.1558
15.559415	-.0092	.1923	3.0508	0.0000	29.1558
15.963556	-.0092	.1886	3.1273	0.0000	29.1558
16.367697	-.0092	.1848	3.2024	0.0000	29.1558
16.771837	-.0092	.1811	3.2760	0.0000	29.1558
17.175978	-.0092	.1774	3.3480	0.0000	29.1558
17.580119	-.0092	.1736	3.4186	0.0000	29.1558
17.984259	-.0092	.1699	3.4876	0.0000	29.1558
18.388400	-.0092	.1662	3.5551	0.0000	29.1558
18.792541	-.0092	.1624	3.6212	0.0000	29.1558
19.196681	-.0092	.1587	3.6857	0.0000	29.1558
19.600822	-.0092	.1550	3.7487	0.0000	29.1558
20.004963	-.0092	.1512	3.8102	0.0000	29.1558
20.409103	-.0092	.1475	3.8702	0.0000	29.1558
20.813244	-.0092	.1438	3.9286	0.0000	29.1558
21.217384	-.0092	.1400	3.9856	0.0000	29.1558
21.621525	-.0092	.1363	4.0411	0.0000	29.1558
22.025666	-.0092	.1326	4.0950	0.0000	29.1558
22.429806	-.0092	.1288	4.1475	0.0000	29.1558
22.833947	-.0092	.1251	4.1984	0.0000	29.1558
23.238088	-.0092	.1214	4.2478	0.0000	29.1558
23.642228	-.0092	.1176	4.2957	0.0000	29.1558
24.046369	-.0092	.1139	4.3421	0.0000	29.1558
24.450510	-.0092	.1102	4.3870	0.0000	29.1558
24.854650	-.0092	.1064	4.4304	0.0000	29.1558
25.258791	-.0092	.1027	4.4723	0.0000	29.1558
25.662932	-.0092	.0990	4.5127	0.0000	29.1558
26.067072	-.0092	.0952	4.5516	0.0000	29.1558
26.471213	-.0092	.0915	4.5889	0.0000	29.1558
26.875354	-.0092	.0878	4.6248	0.0000	29.1558
27.279494	-.0092	.0840	4.6591	0.0000	29.1558
27.683635	-.0092	.0803	4.6919	0.0000	29.1558
28.087776	-.0092	.0766	4.7233	0.0000	29.1558
28.491916	-.0092	.0728	4.7531	0.0000	29.1558
28.896057	-.0092	.0691	4.7814	0.0000	29.1558
29.300198	-.0092	.0654	4.8082	0.0000	29.1558
29.704338	-.0092	.0616	4.8335	0.0000	29.1558
30.108479	-.0092	.0579	4.8572	0.0000	29.1558
30.512620	-.0092	.0542	4.8795	0.0000	29.1558
30.916760	-.0092	.0504	4.9003	0.0000	29.1558
31.320901	-.0092	.0467	4.9195	0.0000	29.1558
31.725042	-.0092	.0430	4.9373	0.0000	29.1558
32.129182	-.0092	.0392	4.9535	0.0000	29.1558
32.533323	-.0092	.0355	4.9682	0.0000	29.1558
32.937464	-.0092	.0318	4.9815	0.0000	29.1558
33.341604	-.0092	.0280	4.9932	0.0000	29.1558
33.745745	-.0092	.0243	5.0034	0.0000	29.1558
34.149886	-.0092	.0206	5.0121	0.0000	29.1558
34.554026	-.0092	.0168	5.0192	0.0000	29.1558
34.958167	-.0092	.0131	5.0249	0.0000	29.1558

30.108479	-.0092	.0579	4.8572	0.0000	29.1558
30.512620	-.0092	.0542	4.8795	0.0000	29.1558
30.916760	-.0092	.0504	4.9003	0.0000	29.1558
31.320901	-.0092	.0467	4.9195	0.0000	29.1558
31.725042	-.0092	.0430	4.9373	0.0000	29.1558
32.129182	-.0092	.0392	4.9535	0.0000	29.1558
32.533323	-.0092	.0355	4.9682	0.0000	29.1558
32.937464	-.0092	.0318	4.9815	0.0000	29.1558
33.341604	-.0092	.0280	4.9932	0.0000	29.1558
33.745745	-.0092	.0243	5.0034	0.0000	29.1558
34.149886	-.0092	.0206	5.0121	0.0000	29.1558
34.554026	-.0092	.0168	5.0192	0.0000	29.1558
34.958167	-.0092	.0131	5.0249	0.0000	29.1558
35.362307	-.0092	.0094	5.0291	0.0000	29.1558
35.766448	-.0092	.0056	5.0318	0.0000	29.1558
36.170589	-.0092	.0019	5.0329	0.0000	29.1558
36.574729	-.0092	-.0018	5.0325	0.0000	29.1558

NATURAL PERIOD 36.030769

MAXIMUM DEFLECTION 5.032911

TIME TO MAXIMUM DEFLECTION 36.372659

DURATION/NATURAL PERIOD .277541

LOAD/RESISTANCE 6.859708

ELASTIC DEFLECTION LIMIT .303740

MAX FRAGMENT SPALL VELOCITY FT/SEC 20.860958
TOTAL COST 3192.18
COUNT 805.00

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NCR 20 Code R31; 20, Commander
NMCB 5, Operations Dept.; THREE, Operations Off.
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NSC Code 54.1 (Wynne), Norfolk VA
NTC Commander Orlando, FL
NUSC Code EA123 (R.S. Munn), New London CT; Code TA131 (G. De la Cruz), New London CT
ONR Code 700F Arlington VA; Dr. A. Laufer, Pasadena CA
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